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AIRCRAFT MEASUREMENTS WITHIN THE PLANETARY BOUNDARY LAYER OVER --ETC(U)
OCT 77 R MARKSON N00019-76-C-0588

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1 OF 2
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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FINAL REPORT

15

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AIRCRAFT MEASUREMENTS WITHIN THE PLANETARY BOUNDARY LAYER OVER WATER

10

Prepared by : Dr. Ralph Markson

Prepared for: Naval Air Systems Command
Washington, D.C. 30361
Code: Air 370/C

In support of: NAVAIR Marine Fog Investigation

391 366

<u>CONTENTS</u>

GENERAL DESCRIPTION

The basic overall objective of ~~our~~ the program has been to develop a relatively inexpensive airborne sensing system for study of the marine boundary layer in support of the NAVAIR Marine Fog Investigation. ~~We~~ This extends into the third dimension measurement of most of the significant parameters which have been studied from ships and land stations. During the contract period we have demsonstrated the capability of operating closely with Navy research ships (ACANIA and HAYES) out to 200 NM from land. We have operated over the Atlantic, Pacific, Gulf of Mexico and over the Potomac River at Dahlgren, Virginia. The operational flexibility of ~~our~~ the aircraft operation has made possible precision dives at constant slant angles to very low altitude over electro-optical sensing instruments at the Naval Surface Weapons Center, Dahlgren, as well as flight into fog at the sea surface in order to obtain complete soundings.

During this contract period we have conducted field measurements and developed instrumentation with seven NAVAIR supported programs. Particular emphasis during our field measurements has been on vertical and horizontal soundings within the surface friction layer over the ocean (10 ft to 100 ft). This region is controlled by mechanical mixing as well as convective processes. We have found it to be completely different than the remainder of the planetary boundary layer; typically turbulence is an order-of-magnitude greater close to the sea surface. This regime has not been investigated from other research aircraft in the past. Because of the capability to fly next to the sea, both within and outside of fog, this region has been included in our soundings. The catalogues of soundings forming the appendices of this report offer a unique body of data characterizing the marine boundary layer over the waters surrounding the United States.

COOPERATIVE PROGRAMS

An overview of our activities during the last year may be derived from a description of cooperative work with the other Navy research groups participating in the Marine Fog/E-O Met Program.

1. Naval Ocean Systems Center, San Diego (Ray Noonkester). During the CEWCOM-1976 field period off Southern California, we worked closely with Ray planning flights in support of the various investigations. Ocean temperatures were mapped and over 100 meteorological soundings were made throughout the test area (frequently close to the R/V ACANIA). Daily weather maps, prepared for us at San Diego, were dropped to the ACANIA. Ray analyzed our sea surface temperatures to derive maps of the ocean isotherm structure which he is using along with our soundings in his research. He, Ken Davidson and I are working on a joint paper studying small-scale, low-level, air-sea interactions. Data for this study comes from the ACANIA, the Bellanca aircraft, and ground instruments on Point Loma.

2. Naval Avionics Facility Indianapolis (Jim Russell). We have operated several versions of the NAFI microwave refractometer and data processing instrumentation during various field investigations including CEWCOM-1976, Panama City, the recent HAYES cruise and flights off the New England coastline. Last June we made a set of detailed soundings off New Hampshire (appendix) which showed the development of a strong inversion during the day close to the water surface. The refractive indes showed radar ducting would have been likely under this low inversion at 50 ft. The flexibility of our operation, e.g., flight in the moist layer next to the ocean and through cumulus clouds, has been particularly advantageous to NAFI in evaluating their instrument. Previously they had to "piggy-back" on Navy aircraft involved in unrelated missions. We also make simultaneous records of the other relevant parameters necessary for evaluation of the refractometer.

3. Postgraduate School, Monterey: Oceanography Department (Dale Leipper). Our CEWCOM-1977 measurements, including soundings through fog and stratus layers and sea surface temperatures, are being used by Dale Leipper and one of his students in analysis of West Coast fog. Dale has indicated that this is the first time he has been able to get such soundings which he needs for his research.

4. Postgraduate School, Monterey: Meteorology and Physics Departments (Ken Davidson, Chris Fairall and Gordon Schacher). We are working closely with this group extending their previously surface bound burbulence measurements up through the marine layer. C_t (temperature turbulence structure function coefficient) soundings have been obtained over the Atlantic, Pacific, Gulf of Mexico, an inland river (Dahlgren) and over land. The height range extends from 10 ft to 32,000 ft. Surprisingly we have found at times more temperature turbulence above the inversion than within the planetary boundary layer--except for the surface friction layer which generally exhibits a large increase in C_t; see for example Figs. 15 and 18 of our "CEWCOM-1976 & Panama City-1977" report (appendix). Not surprisingly we observe a great increase in C_t at low altitudes

over heated land compared to over water (Fig. 19). These measurements are difficult to obtain from an airplane; as far as we know there are only two or three other aircraft with the capability in the U.S. We come together with the PGS group frequently in development of the turbulence instrumentation. Ken Davidson and Chris Fairall have visited several times with us in Boston. Dr. Fairall has been present at each of our field periods. He also has participated in flight tests. We are trying to improve the C_t instrumentation while developing the capability to measure ϵ (the velocity turbulence structure function coefficient) from the aircraft.

5. Calspan Corp. (Gene Mack). During CEWCOM-1976 we obtained soundings upwind, within, and downwind of fog since these measurements are of particular interest to the Calspan group in their fog medelling. In their previous West Coast experiment, the Calspan aircraft was unable to make such soundings. Figures 5 through 8 of the CEWCOM-1976 report depicts some of these measurements.

6. Naval Research Laboratory (Lothar Ruhnke). We accompanied the USN HAYES from Virginia up the Atlantic coastline past Nova Scotia during their investigation of the characteristics of t he marine boundary layer in different regions. Soundings through this layer were obtained close to the ship and dropped to them.

7. Coastal Studies Institute. We participated in a study of the marine boundary layer off Panama City during February 1977. Navair supported participating groups included NAFI and Calspan. Sea surface temperatures and soundings were obtained through the test area. A study of the effects of the atmosphere on remote sea surface temperature sensing is being done with Oscah Huh of CSI (Louisiana State University) who is analyzing simultaneous aircraft, ground truty (ship) and satellite observations. One of the interesting observations made was that a moist layer only 100 ft thick at the sea surface can cause a change in sensed sea surface temperature of 1 degree C (Fig. 12). We also observed significant variations in sensed temperature on the aircraft as a function of altitude--sometimes with opposite effects from one day to the next, i.e., sensed SST increases with altitude in Fig. 7 while it decreases with altitude in Fig. 13.

8. High Energy Program (Lt. Michelle Hughes). In support of a target imaging investigation held at Dahlgren, Virginia, we made measurements of C_t and other relevant parameters during April 1977. New C_t equipment was tried in conjunction with Chris Fairall who came from Monterey to participate in this development work. Results of this program have been compiled into a separate report which is given as an appendix.

AIRCRAFT OPERATIONS

Our aircraft can be flown within the surface friction layer over the ocean. Extended duration flight at 10 ft above the surface is accomplished routinely. This capability facilitates study of the air-sea interface, a region which in the past has only been studied from ships and fixed platforms. We have found that meteorological conditions within 50 to 100 ft of the surface are generally different than higher in the marine boundary layer. For example, turbulence moisture, aerosol loading and atmospheric space charge can undergo order of magnitude increases descending through the surface layer. This is important for the E-O Met Program since most sensors are positioned close to, or at, the ground or sea level, and most optical paths may be through this surface boundary layer. Because of the extreme low altitude flight capability it has been possible to develop a technique for obtaining complete aircraft soundings through marine fog,(e.g., Fig. 6). This is accomplished in the open sea away from shipping lanes by penetrating fog banks from the side at an altitude of 10 to 20 ft. As long as visibility is at least 100 ft the aircraft can be flown by visual reference to the sea surface. When visibility becomes less, or when it is desired to obtain a profile (typically a few miles within the fog) the aircraft is flown upward in a spiral path. This procedure was developed because inaccuracies in aircraft altimetry make it unsafe to descend to the surface through fog.

The mode of aircraft operation provides unusual flexibility and maximizes data quality. Decisions on flight paths are made while collecting the data to optimize the investigation. Observation of interactions by the aircraft systems on the measurements can be made by the scientist and observer operating the aircraft and instrumentation. This is because the parameters are recorded in analog form on a multichannel oscillograph. For example, we have been able to identify noise (apparently acoustic pickup) in the C_t measurement which resulted from changes in the propeller pitch setting. This was possible because the pilot working the engine controls observed simultaneously that the chart trace varied when the propeller was adjusted. This source of noise was eliminated by relocating the C_t sensing wires from mid-wing to the wingtip. This source of noise would have gone undetected on the typical multi-engine research aircraft with observers riding in the rear. Temperature inversions and dew point discontinuities can be identified immediately and flight paths adjusted accordingly. Roll vortices occupying the boundary layer are detected in real-time when we observe periodic variations in the electric field trace. Then crosswind and up/downwind passes are made to study the phenomenon.

INSTRUMENTATION

The Bellanca aircraft is instrumented to measure the following:

1. air temperature (Rosemont probe)
2. dew point temperature (Panametrics probe to be replaced with Thunder Scientific instrumentation)
3. refractive index of air (NAFI microwave refractometer)
4. infra -red sea surface temperature (Barnes PRT-5 precision radiation thermometer)
5. C_t temperature turbulence structure function (Thermo Systems Inc. instrumentation provided by PGS, to be replaced by instrumentation we will design)
6. visibility (Meteorology Research Inc. integrating nephelometer)
7. altitude (aneroid pressure transducer and aircraft's altimeter)
8. atmospheric electrical potential gradient (electrometer with radioactive probe antennas)
9. atmospheric electrical conductivity (Gerdien tube)
10. distance from VOR navigation station (DME distance measuring equipment)
11. azimuth from VOR navigation station (OMNI navigation receivers)
12. heading (slaved gyro compass with no precession)

There have been problems with some of the instrumentation and in the next year we plan a major effort to improve our measuring capabilities. New instruments will be added and an instrumentation engineer has been hired to facilitate the instrumentation development program.

A new dew point sensing system will replace the old one which was found to change calibration.

The atmospheric electric instruments are being redesigned using new solid state technology. The new engineer was selected because of his strong background in designing anamometers which use ultra-thin wires as sensors similar to the C_t measuring system. Although apparently we have the best airborne capability for making this measurement, there still is considerable noise in the system some of which comes from the aircraft installation. New electronic circuitry including a specially designed low noise inverter should greatly imporve the situation. Working with Chris Fairall, we have attempted to measure ϵ , the velocity turbulence structure function, but so far only have been successful when flying next to the ocean surface. This is because here the signal is sufficiently

Publications and Presentations

The following reports have been given (or planned) using data from our program during the contract period:

1. "Santa Anna Associated Offshore Fog: Forecasting with a Sequential Model",Douglas Allen Backes (in conjunction with Dale Leipper), Tech. Rept. No. NPS-68LR77091, Naval Postgraduate School Monterey, Calif., Dept of Oceanography, Sept. 1977.

2. Joint paper on observations of the development and characteristics of the "mixed layer" over the ocean off San Diego, authors Noonkester, Markson and Davidson, in preparation.

3. "Altitude Dependence of C_t^2 Over the Ocean", C.W. Fairall, R. Markson and J. Sedláček, Tech. Rept. No. NPS-61FR77101, Naval Postgraduate School, Monterey, Calif., Dept. of Meteorology, Oct. 1977, 43 pp. (submitted for publication).

4. "Measurements of Altitude Dependence of Atmospheric Turbulence", C.W. Fairall, R. Markson and J. Sedláček, persented at conference on Optical Properties Through Turbulence, Rain, and Fog, Univ. Colorado, Boulder, 9-11 Aug. 1977, abstract in TUC 3-1, Optical Society of America.

5. Reports in preparation by J. Russell, Naval Avionics Facility, Indianapolis, Indiana.

6. "Atmospheric Electrical Plume Detection: Theory and Field Measurements", R. Markson, D. Blumenthal and J. Sedláček, presented at conference on Aerial Techniques for Environmental Monitoring, Las Vegas, Nevada, 7-11 March, 1977.

APPENDICES

1. Cewcom-1976 and Panama City-1977: Report on Measurements During 1976 as Part of the Marine Fog Investigation.

2. Temporal Variation of the Fine Structure of the Marine Boundary Layer (Temperature, Dew Point, and Refractive Index) off New England during June 1977.

3. Atmospheric Structure over the Test Range at the Naval Surface Weapons Center, Dahlgren, Virginia.

AIRBORNE RESEARCH ASSOCIATES
46 KENDAL COMMON ROAD • WESTON, MASSACHUSETTS 02193 • (617) 899-1834

CEWCOM-1976 & PANAMA CITY-1977

REPORT ON MEASUREMENTS DURING 1976 AS PART OF
THE MARINE FOG INVESTIGATION

by

Ralph Markson, Ph.D.

A catalog of aircraft soundings
through the marine boundary layer.

Prepared under Naval Air Systems Command Contract No. N00019-76-C-0588
Fifth Annual Marine Fog Investigation Program Review
Calspan Corporation, Buffalo, N.Y. (5-6 April 1977)

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NOTES

A. The following parameters have been measured:

1) temperature (Rosemount probe)
2) dew point (Panametrics aluminum oxide probe)
3) infra-red sea surface temperature (Barnes PRT-5)
4) C_t^2 (temperature turbulence coefficient)
5) refractive index of air (NAFI microwave refractometer)
6) vertical electric field intensity (radioactive probes)
7) conductivity (Gerdien tube)

B. The dew point measurement is apparently 2 to 4 degrees high and no dew point data are available above 10 C as the instrument saturated at that point. The relative variations however are believed accurate and more sensitive (faster response, 1 to 2 sec) than other dew point sensing systems.

C. The aircraft's temperature sensor is believed accurate as it has been checked against other thermometers during flight. The balloon air temperature, Fig. 4, is probably low by about 3 C.

D. The C_t^2 values are somewhat high as at the time of preparation of this report we did not know the residual "noise" coming from the aircraft and electronics. These figures have been established during late April 1977 and will be reflected in future data reduction. The C_t^2 values here therefore are of most interest in showing relative changes with altitude and indicate a generally not recognized fact that C_t^2 can have higher values above 3 km than in the "exchange layer" below that. Another regime we have defined where C_t^2 becomes large discontinuously is close to the ocean surface where our soundings have been made down to a height of 3 m.

CONTENTS

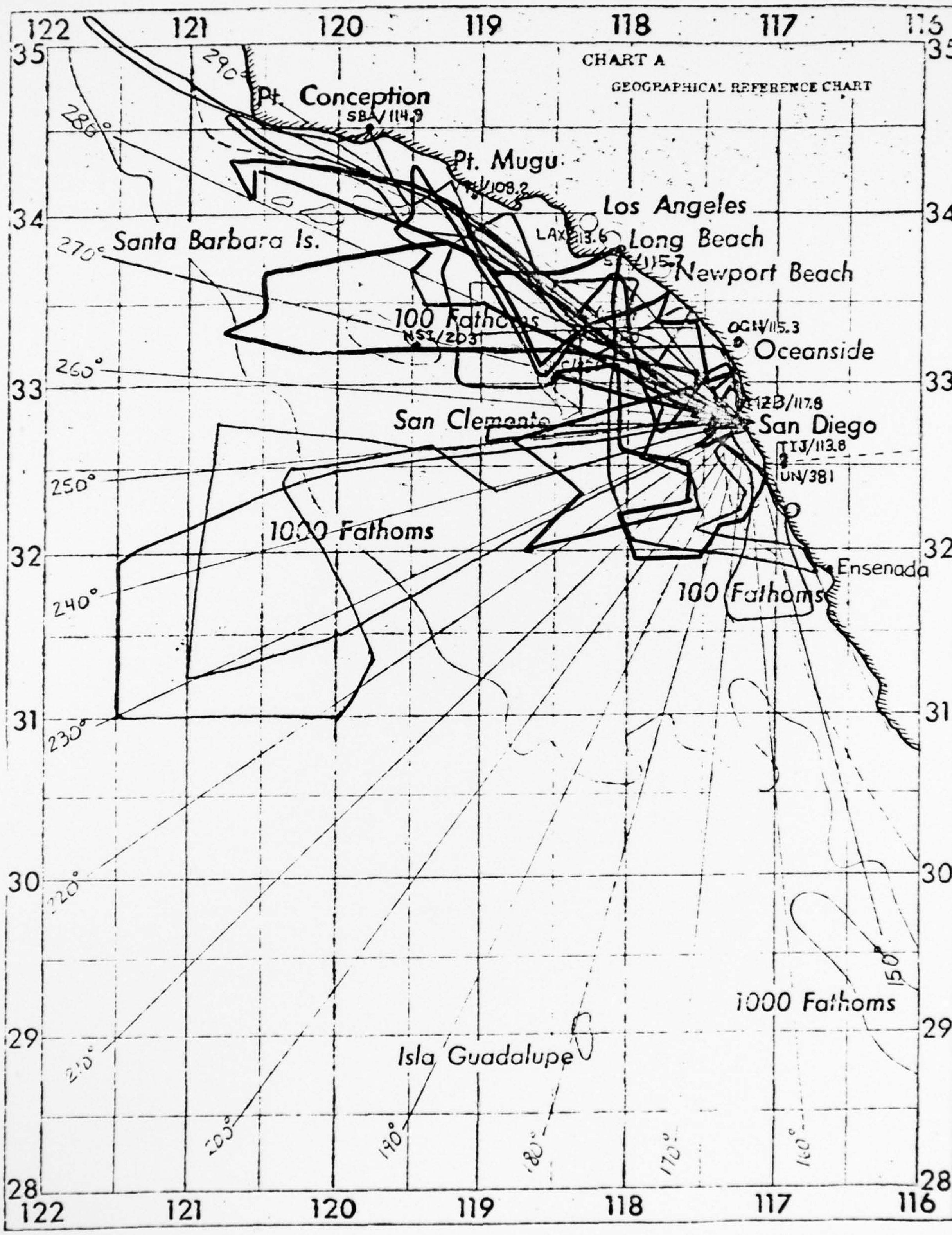
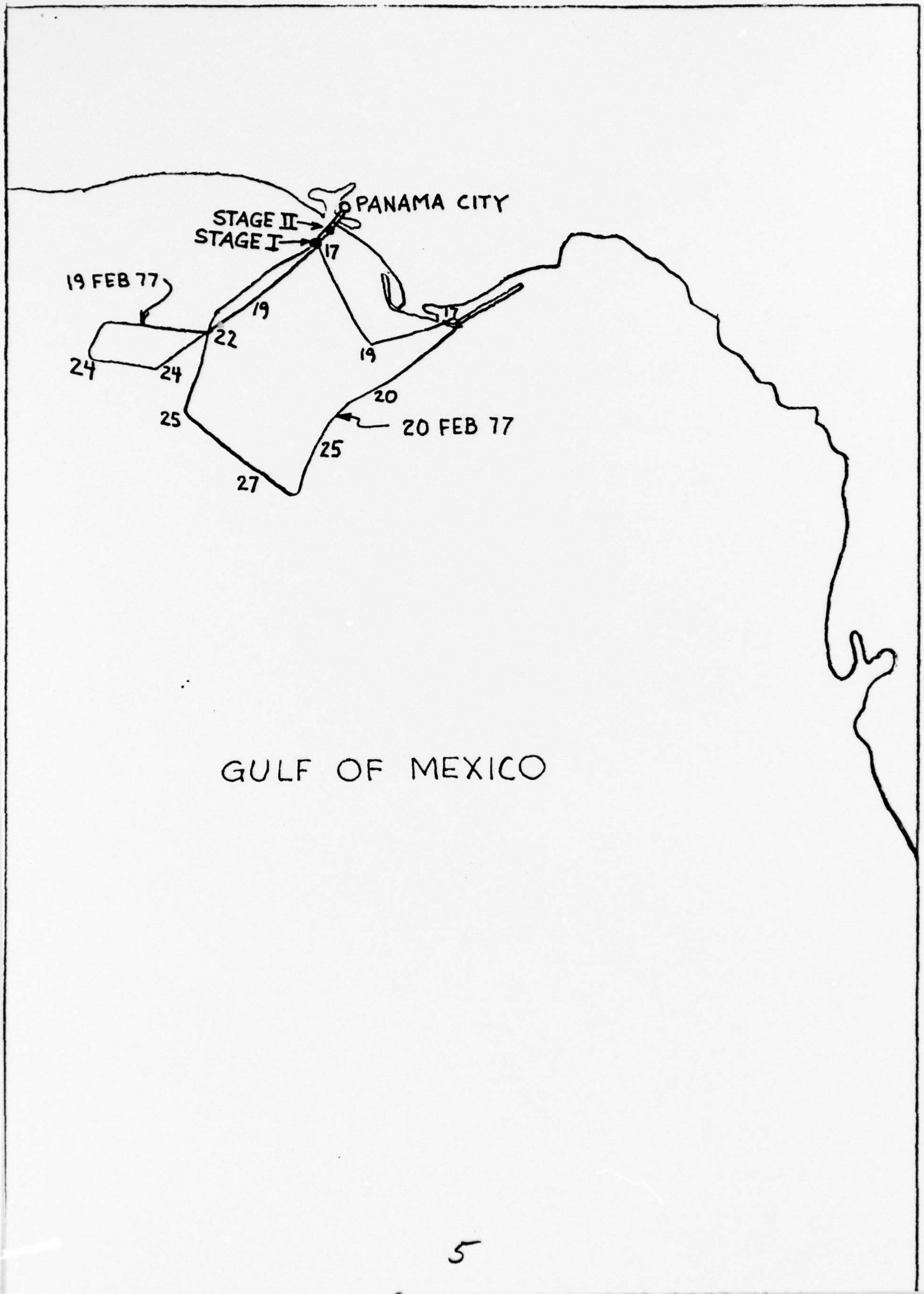
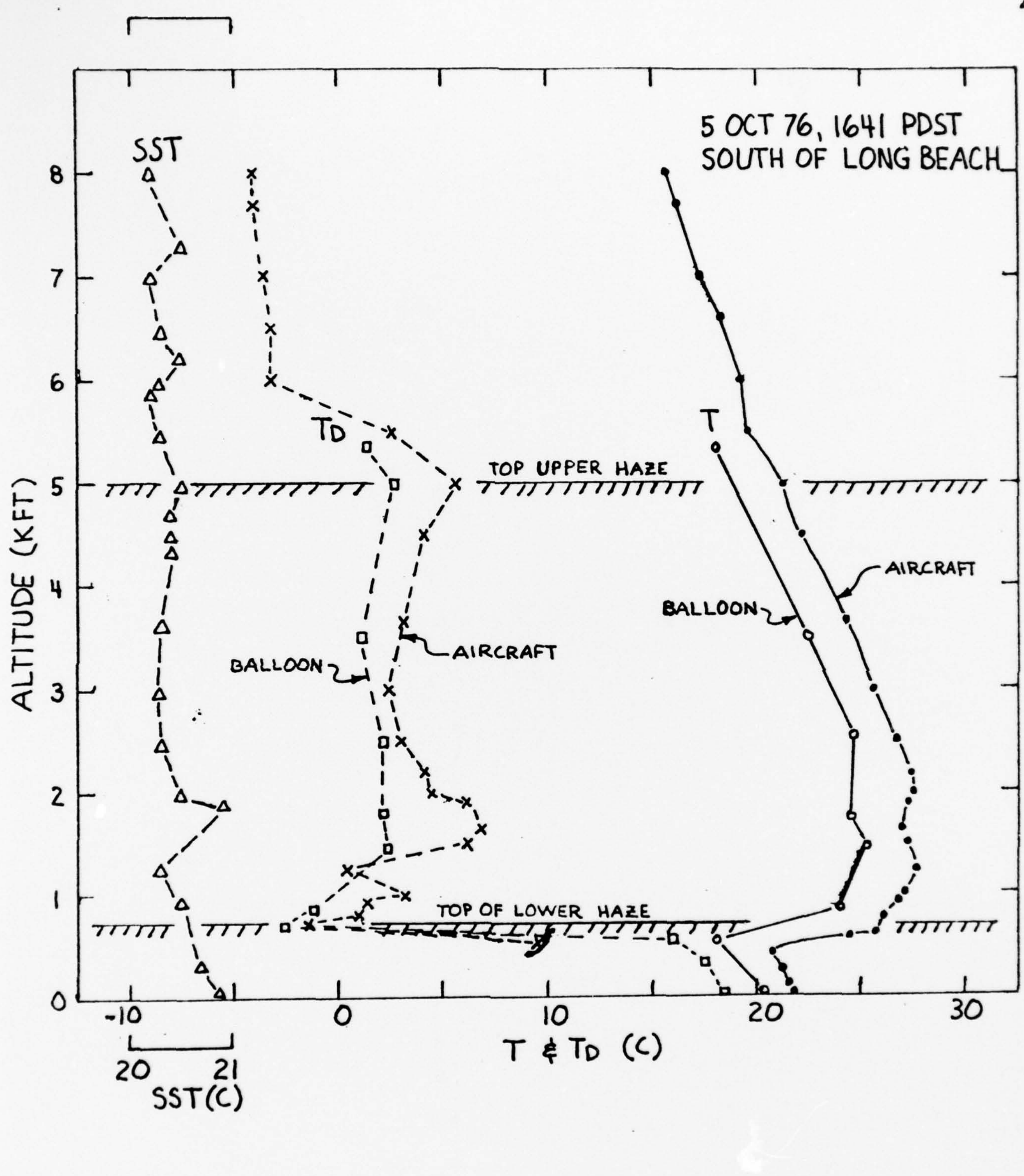
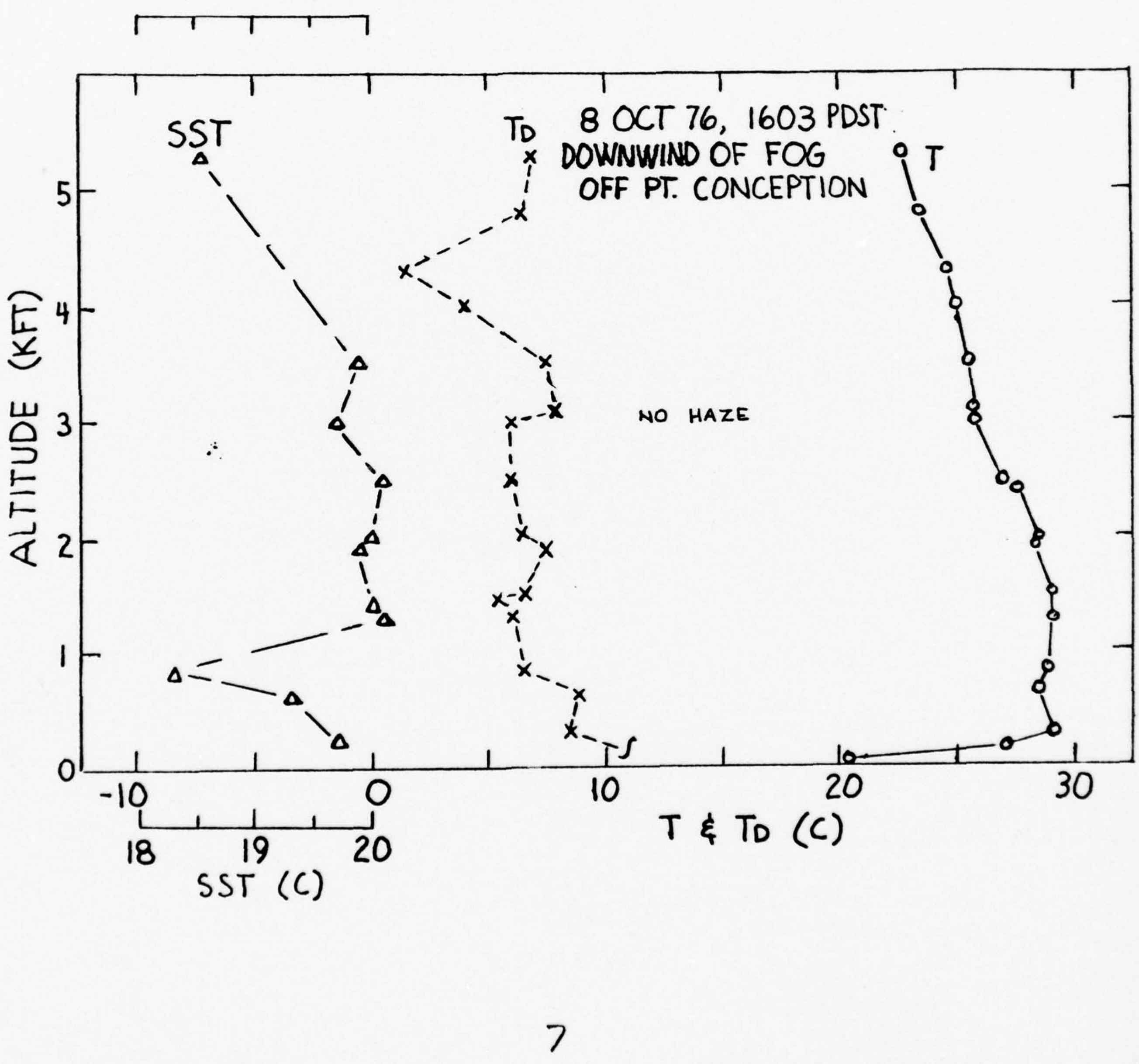
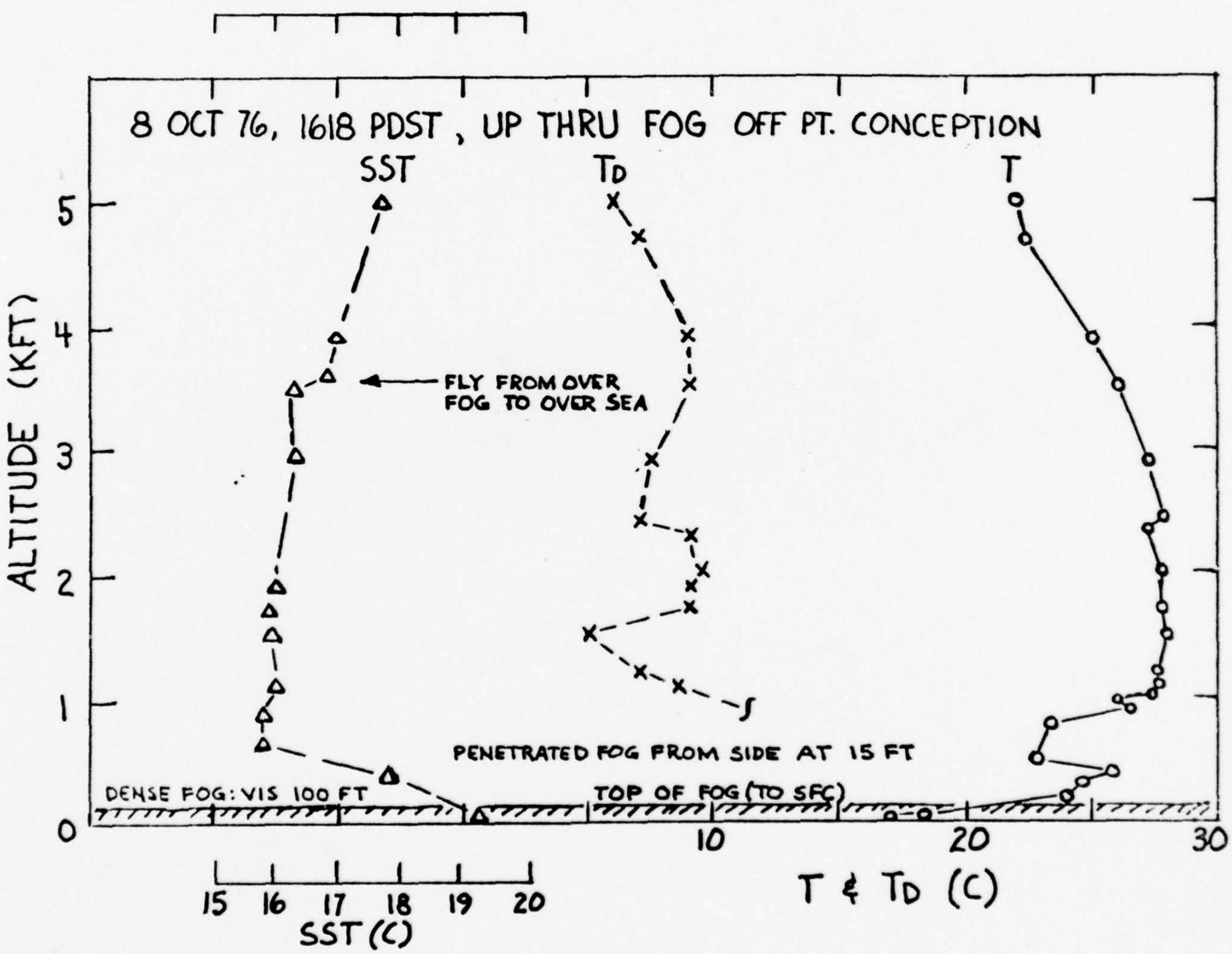


CHART A
GEOGRAPHICAL REFERENCE CHART
Pt. Conception
SBA/114.9
Pt. Mugu
Los Angeles
Long Beach
Newport Beach
Santa Barbara Is.
100 Fathoms
NSI/203
Oceanside
San Clemente
San Diego
TIJ/113.8
UN/381
1000 Fathoms
Ensenada
100 Fathoms
1000 Fathoms
Isla Guadalupe
122
121
120
119
118
117
116
35
34
33
32
31
30
29
28
290°
280°
270°
260°
250°
240°
230°
220°
210°
200°
190°
180°
170°
160°
150°

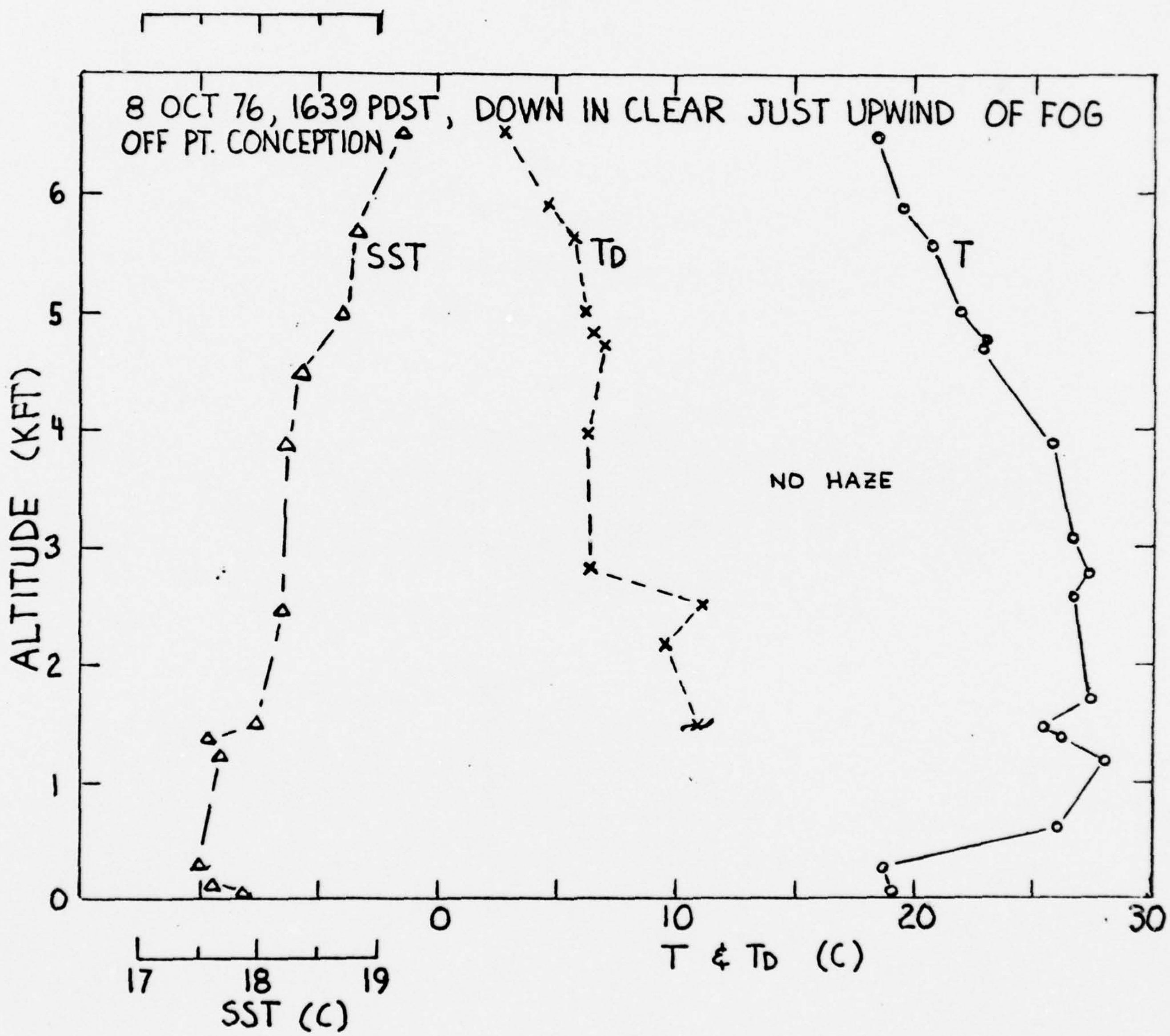

PANAMA CITY
STAGE II
STAGE I
17
19 FEB 77
19
22
24
24
25
27
17
19
20
20 FEB 77
25
GULF OF MEXICO

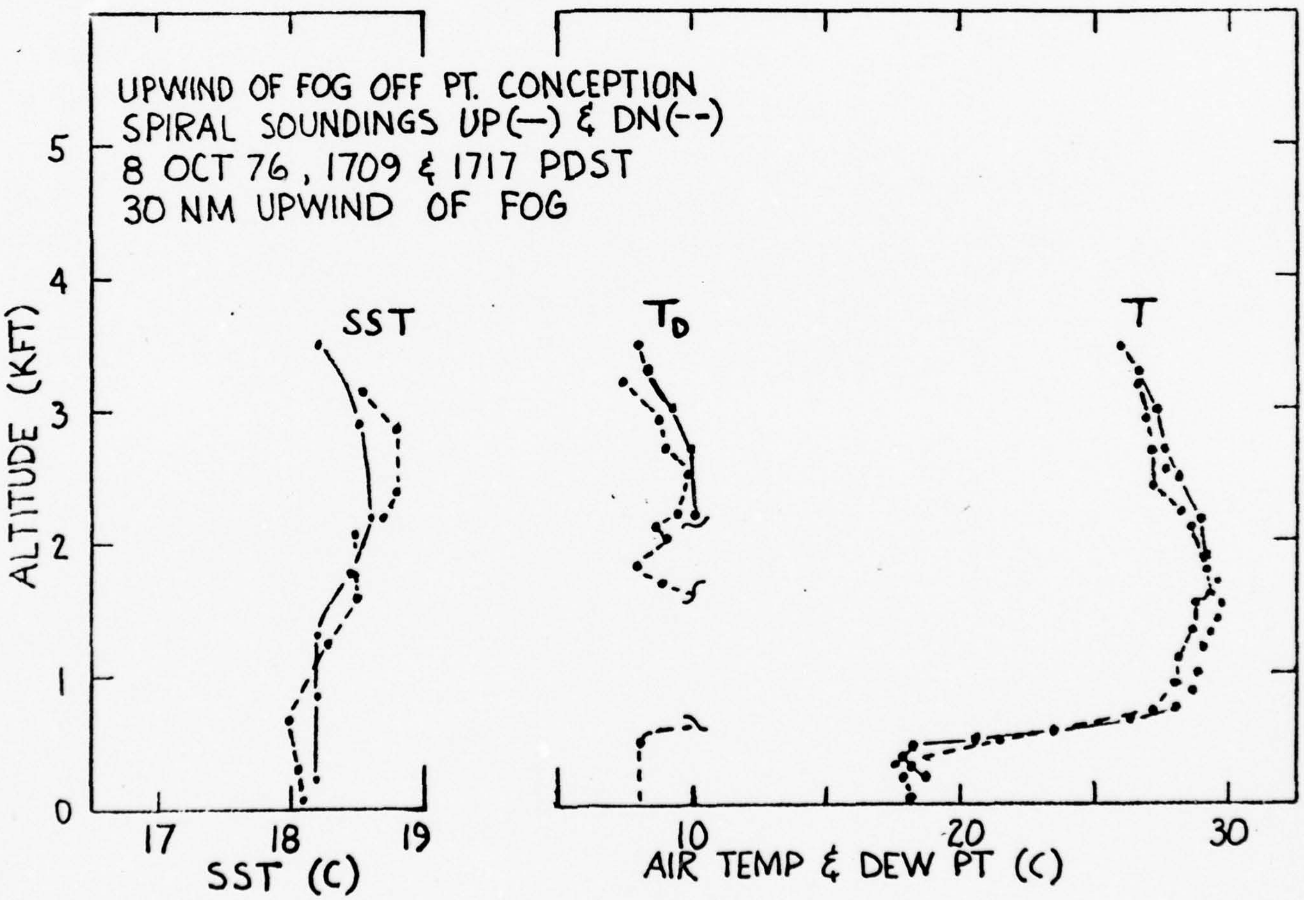

5 OCT 76, 1641 PDST
SOUTH OF LONG BEACH
SST
TD
T
TOP UPPER HAZE
TOP OF LOWER HAZE
AIRCRAFT
BALLOON
AIRCRAFT
BALLOON
ALTITUDE (KFT)
0
1
2
3
4
5
6
7
8
-10
0
10
20
30
T & TD (C)
20
21
SST(C)

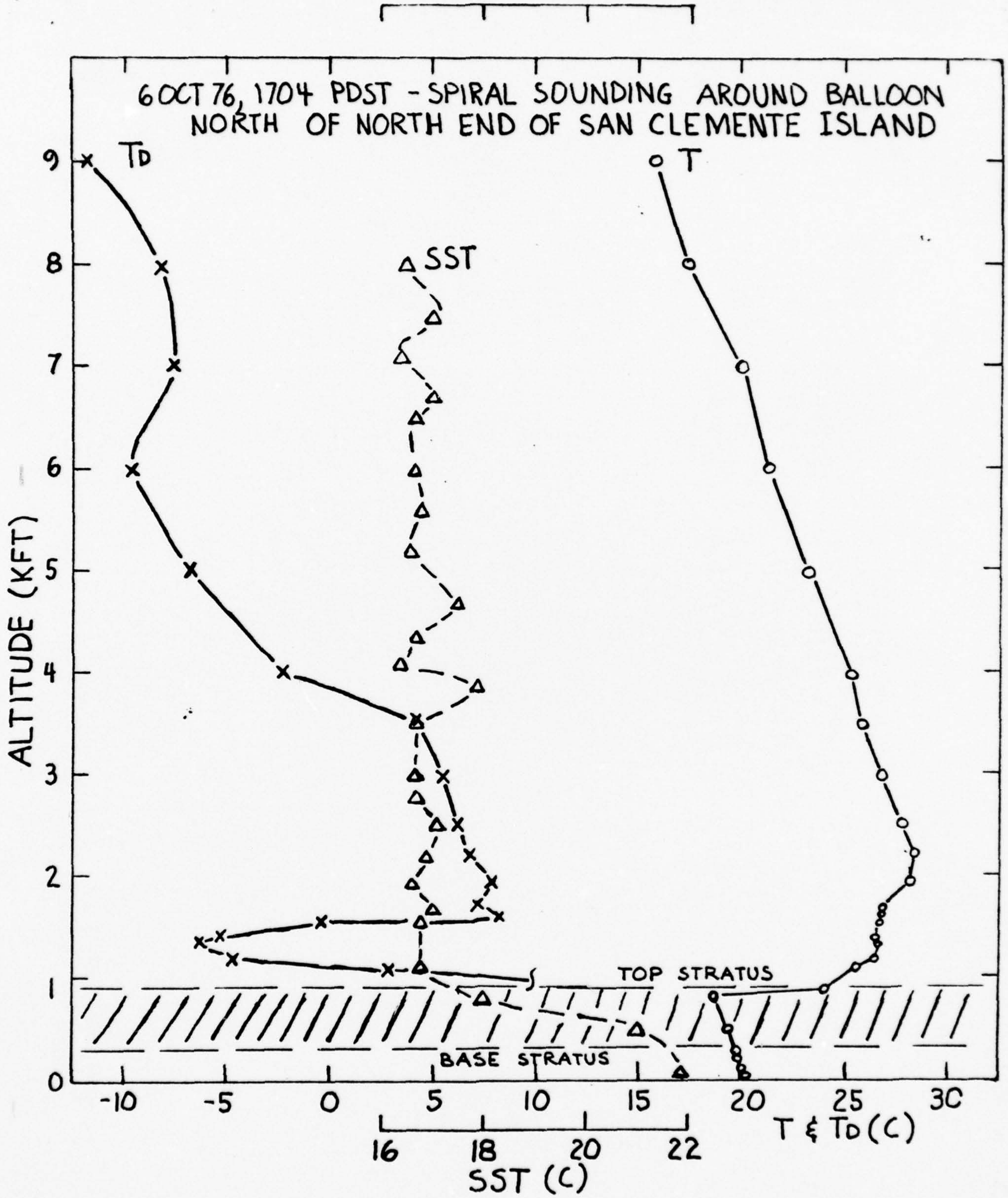

8 OCT 76, 1603 PDST
DOWNWIND OF FOG
OFF PT. CONCEPTION
SST
TD
T
NO HAZE
ALTITUDE (KFT)
0
1
2
3
4
5
-10
0
10
20
30
T & TD (C)
18
19
20
SST (C)

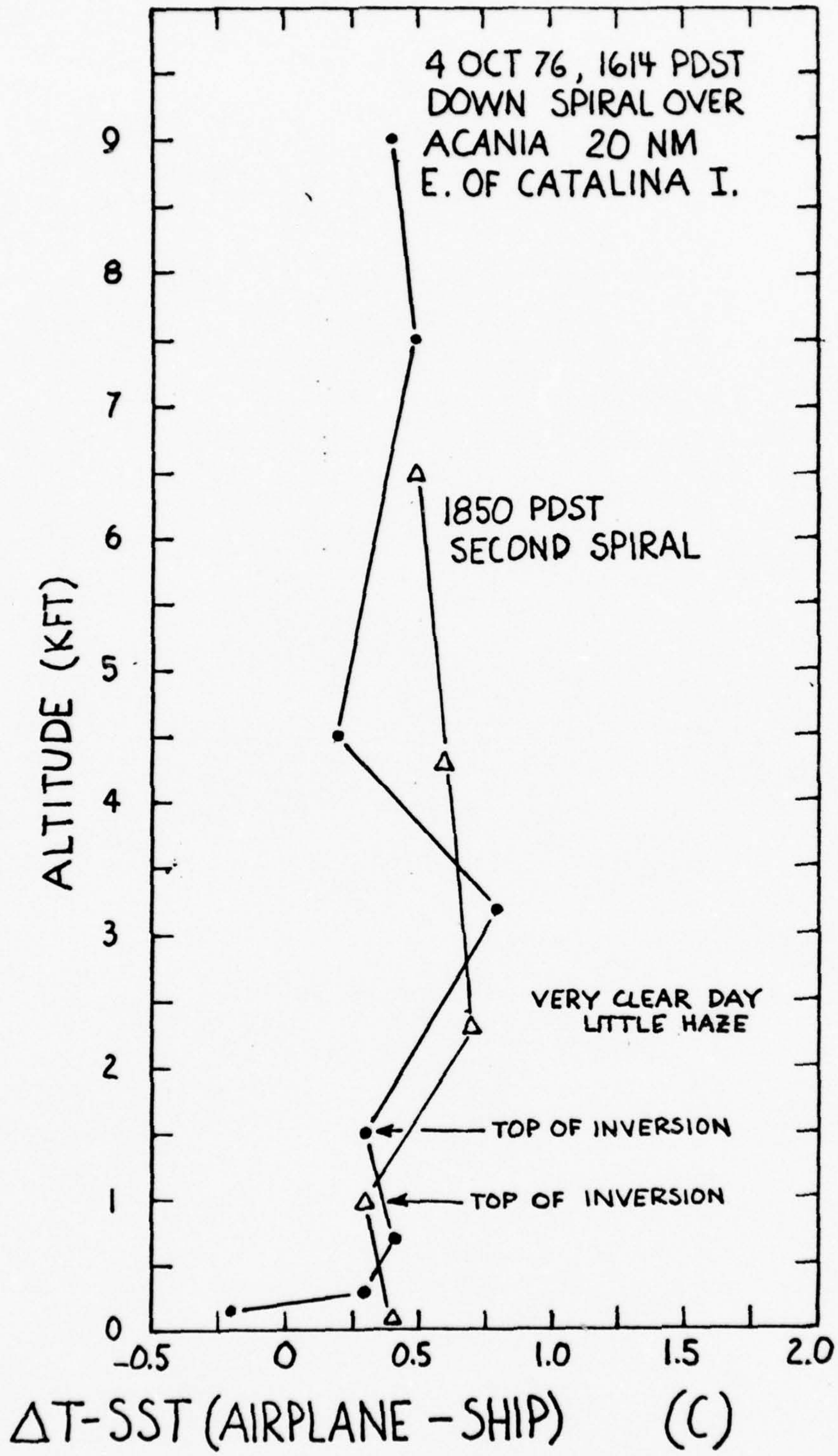


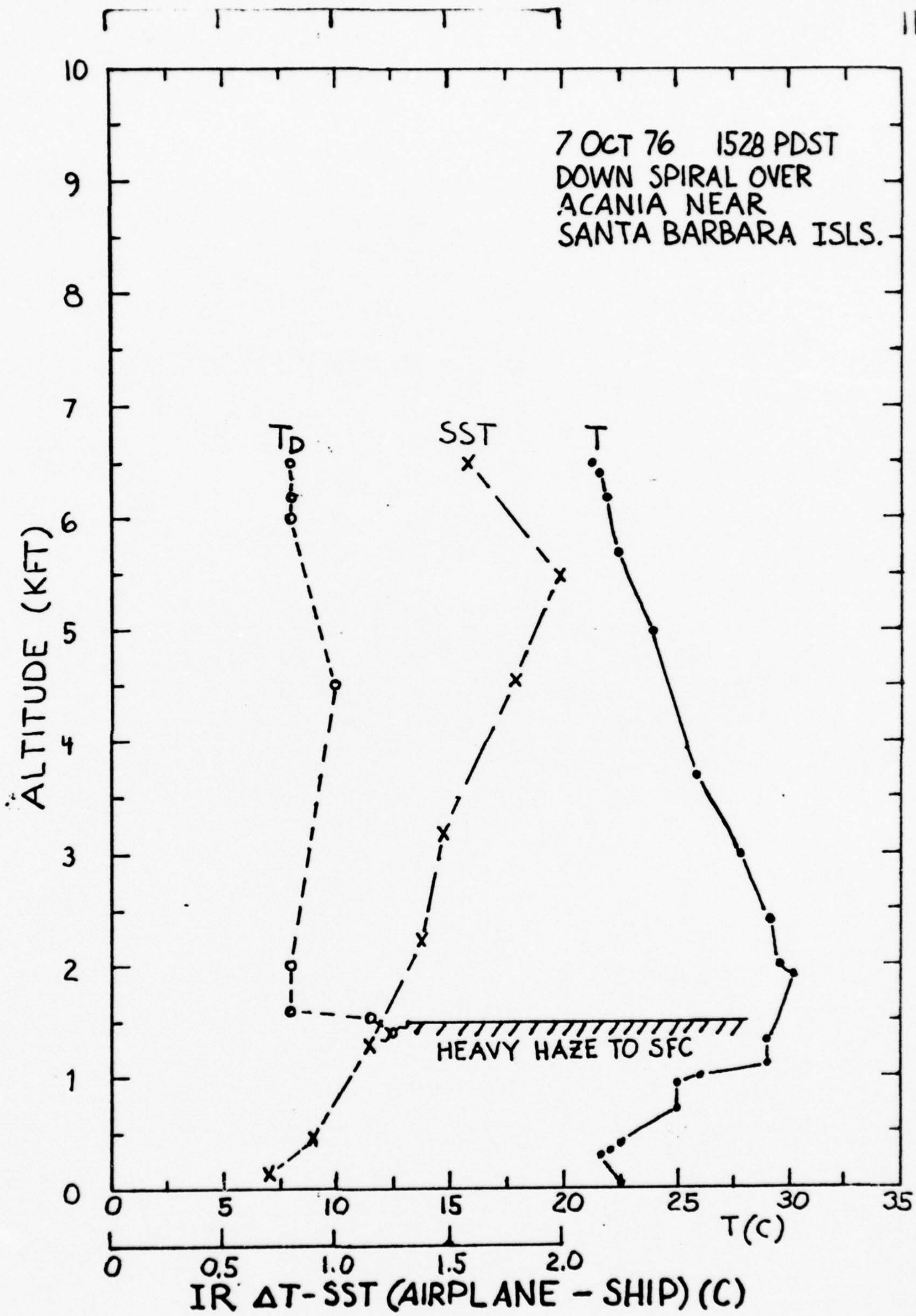
8 OCT 76, 1618 PDST, UP THRU FOG OFF PT. CONCEPTION
SST
TD
T
ALTITUDE (KFT)
FLY FROM OVER FOG TO OVER SEA
PENETRATED FOG FROM SIDE AT 15 FT
DENSE FOG: VIS 100 FT
TOP OF FOG (TO SFC)
0
1
2
3
4
5
10
20
30
T & TD (C)
15
16
17
18
19
20
SST (C)

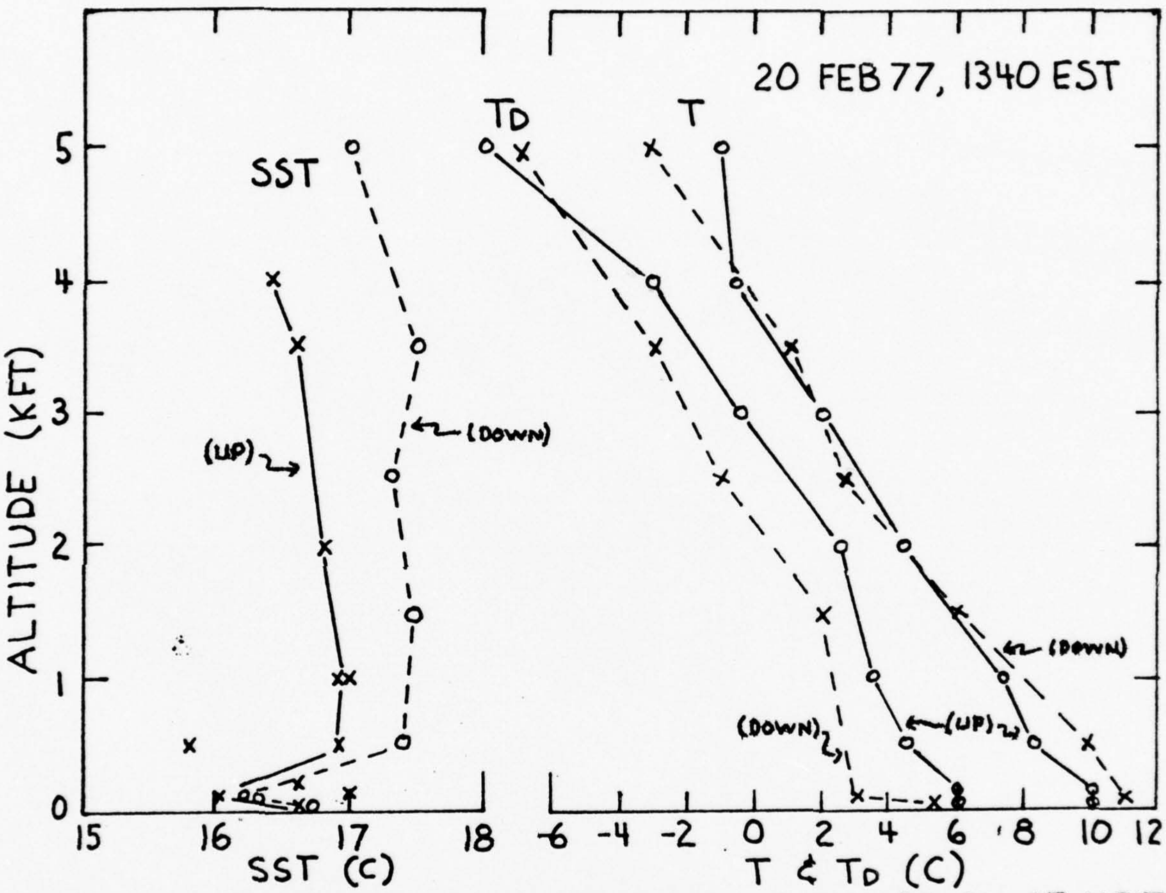

8 OCT 76, 1639 PDST, DOWN IN CLEAR JUST UPWIND OF FOG
OFF PT. CONCEPTION
SST
TD
T
NO HAZE
ALTITUDE (KFT)
0
1
2
3
4
5
6
0
10
20
30
T & TD (C)
17
18
19
SST (C)


UPWIND OF FOG OFF PT. CONCEPTION
SPIRAL SOUNDINGS UP(—) & DN(--)
8 OCT 76, 1709 & 1717 PDST
30 NM UPWIND OF FOG
SST
T_D
T
ALTITUDE (KFT)
0
1
2
3
4
5
17
18
19
SST (C)
10
20
30
AIR TEMP & DEW PT (C)

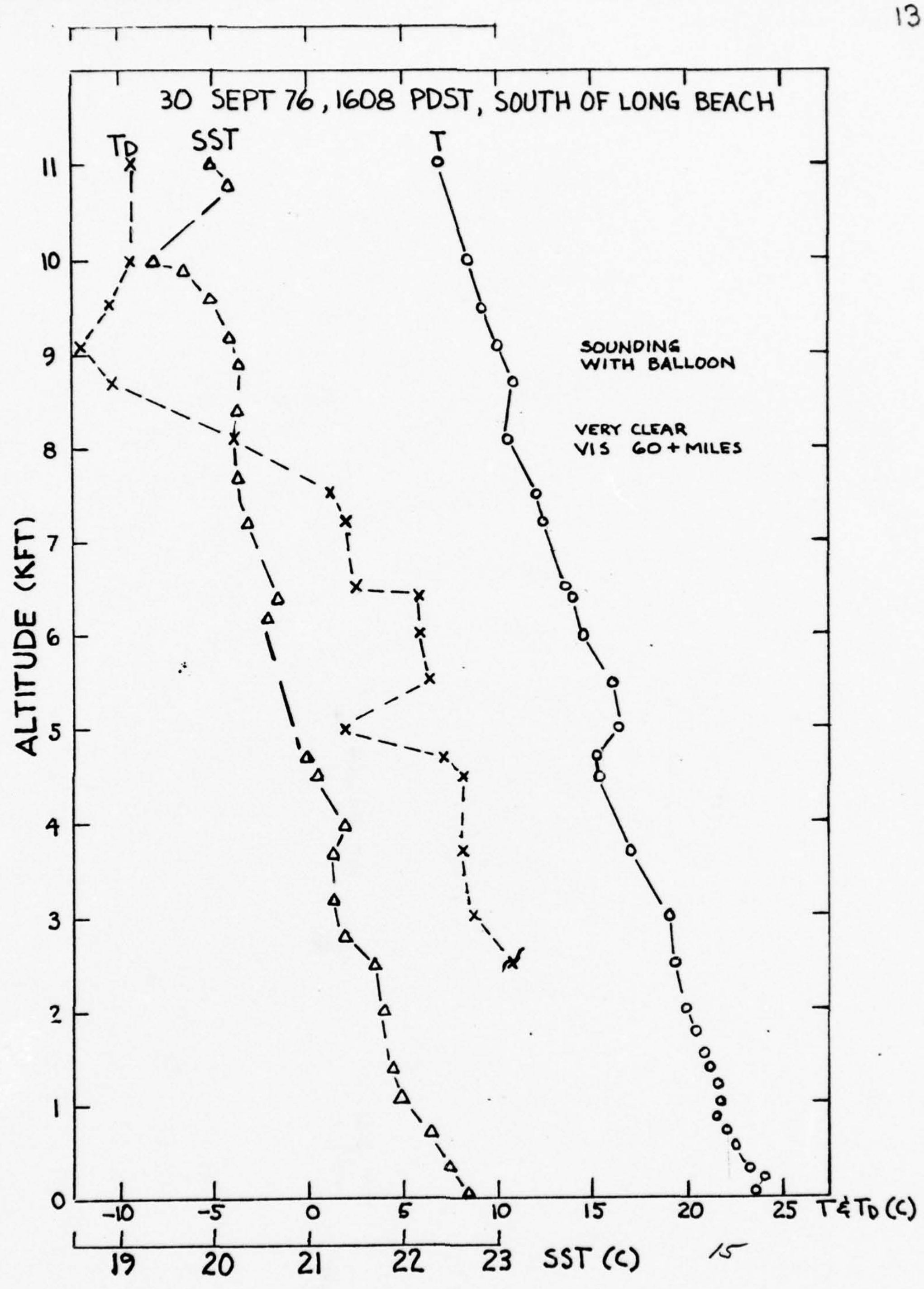

6 OCT 76, 1704 PDST - SPIRAL SOUNDING AROUND BALLOON
NORTH OF NORTH END OF SAN CLEMENTE ISLAND
TD
T
SST
TOP STRATUS
BASE STRATUS
ALTITUDE (KFT)
0
1
2
3
4
5
6
7
8
9
-10
-5
0
5
10
15
20
25
30
T & TD (C)
16
18
20
22
SST (C)


4 OCT 76, 1614 PDST
DOWN SPIRAL OVER
ACANIA 20 NM
E. OF CATALINA I.
1850 PDST
SECOND SPIRAL
VERY CLEAR DAY
LITTLE HAZE
TOP OF INVERSION
TOP OF INVERSION
ALTITUDE (KFT)
0
1
2
3
4
5
6
7
8
9
-0.5
0
0.5
1.0
1.5
2.0
ΔT-SST (AIRPLANE - SHIP) (C)

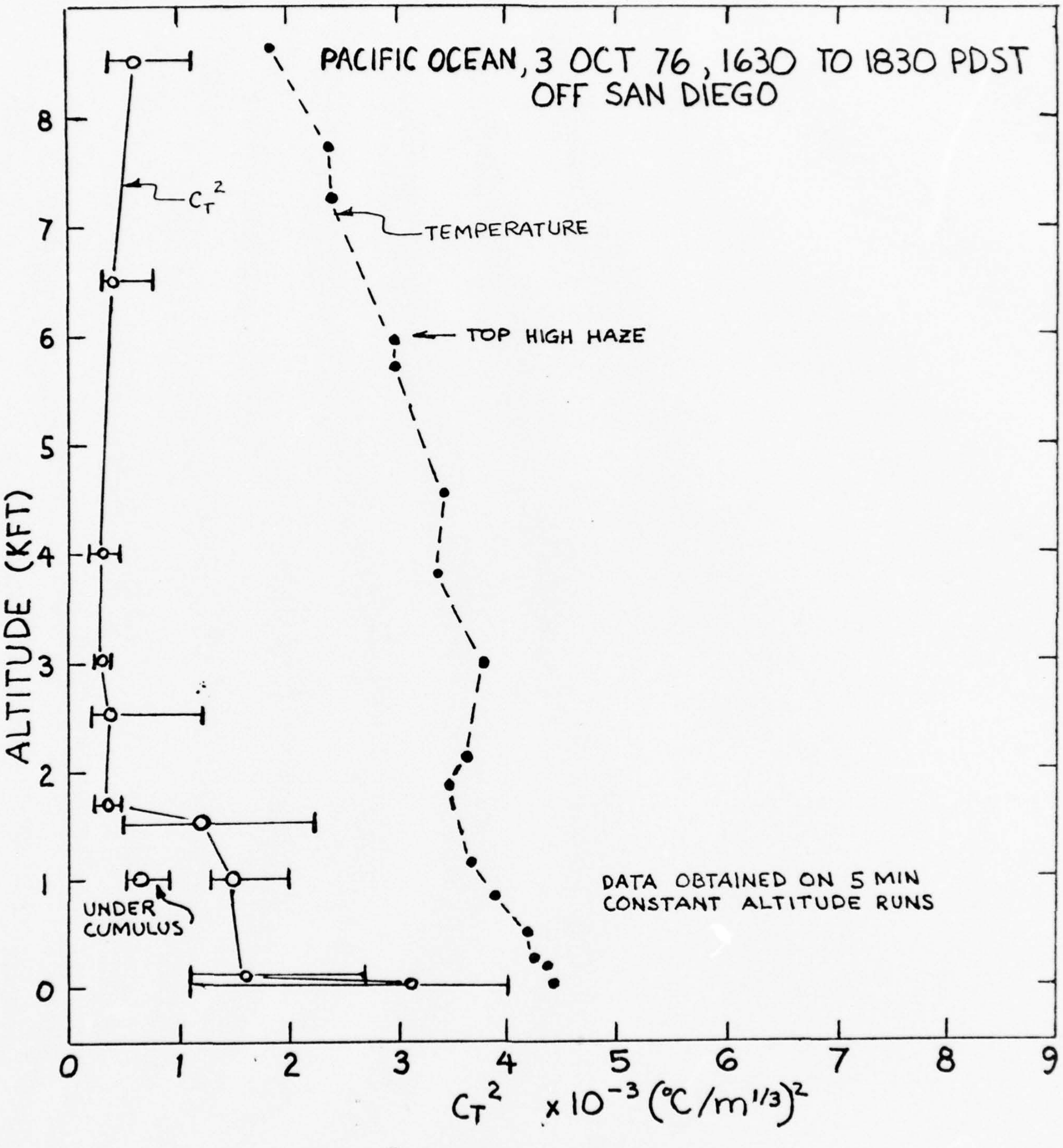

7 OCT 76 1528 PDST
DOWN SPIRAL OVER
ACANIA NEAR
SANTA BARBARA ISLS.
ALTITUDE (KFT)
TD
SST
T
HEAVY HAZE TO SFC
T(C)
IR ΔT-SST (AIRPLANE - SHIP) (C)
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30
35
0
0.5
1.0
1.5
2.0



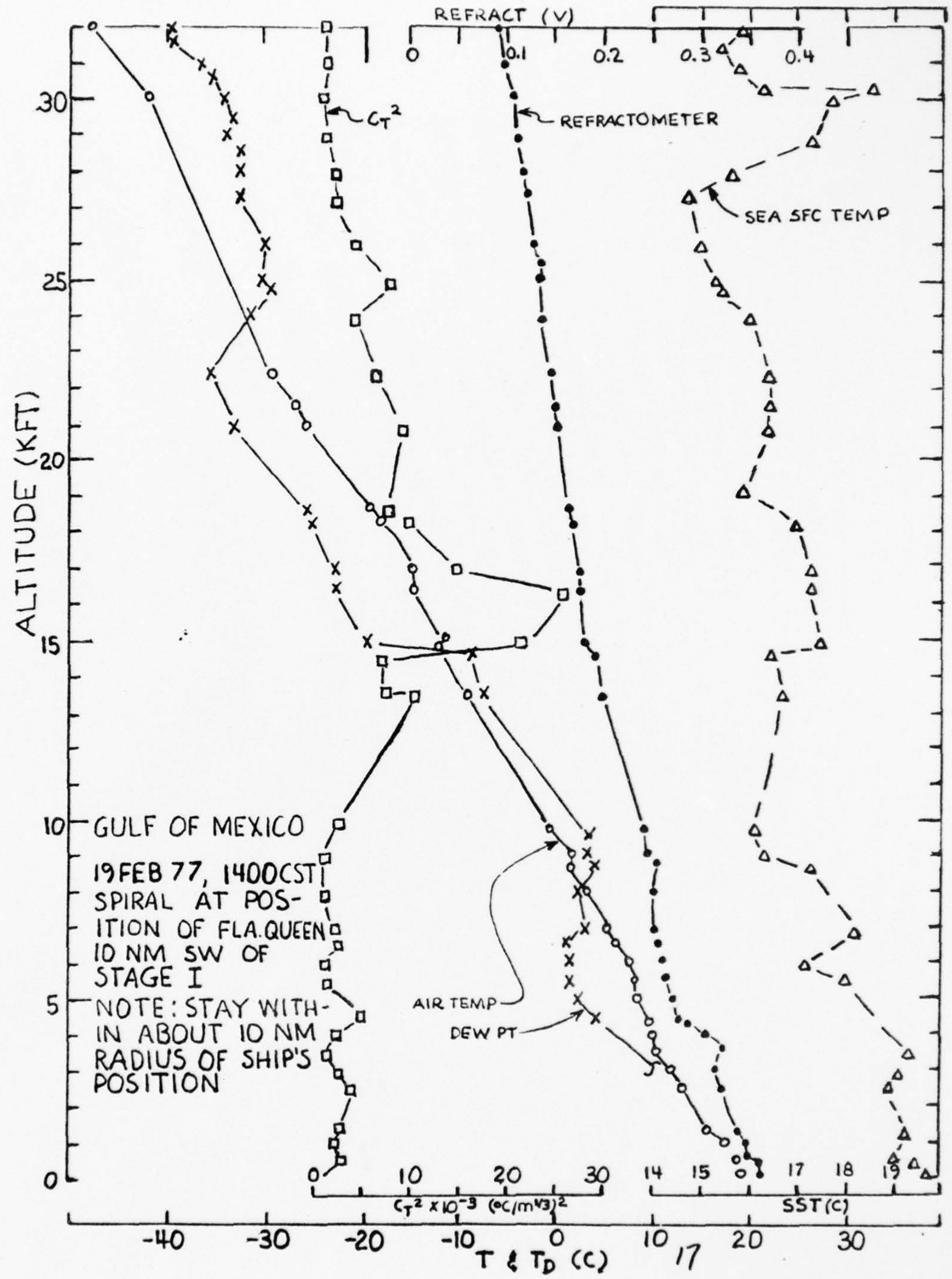
VARIATION OF IR-SST FROM AIRCRAFT AS FUNCTION OF ALTITUDE; MEASUREMENTS MADE OVER FLORIDA QUEEN NEAR STAGE ONE PLATFORM OFF PANAMA CITY, FLA. WHEN SHIP BUCKET TEMPERATURE = 13.8 C AND SATELLITE TEMPERATURE = 10.5 C

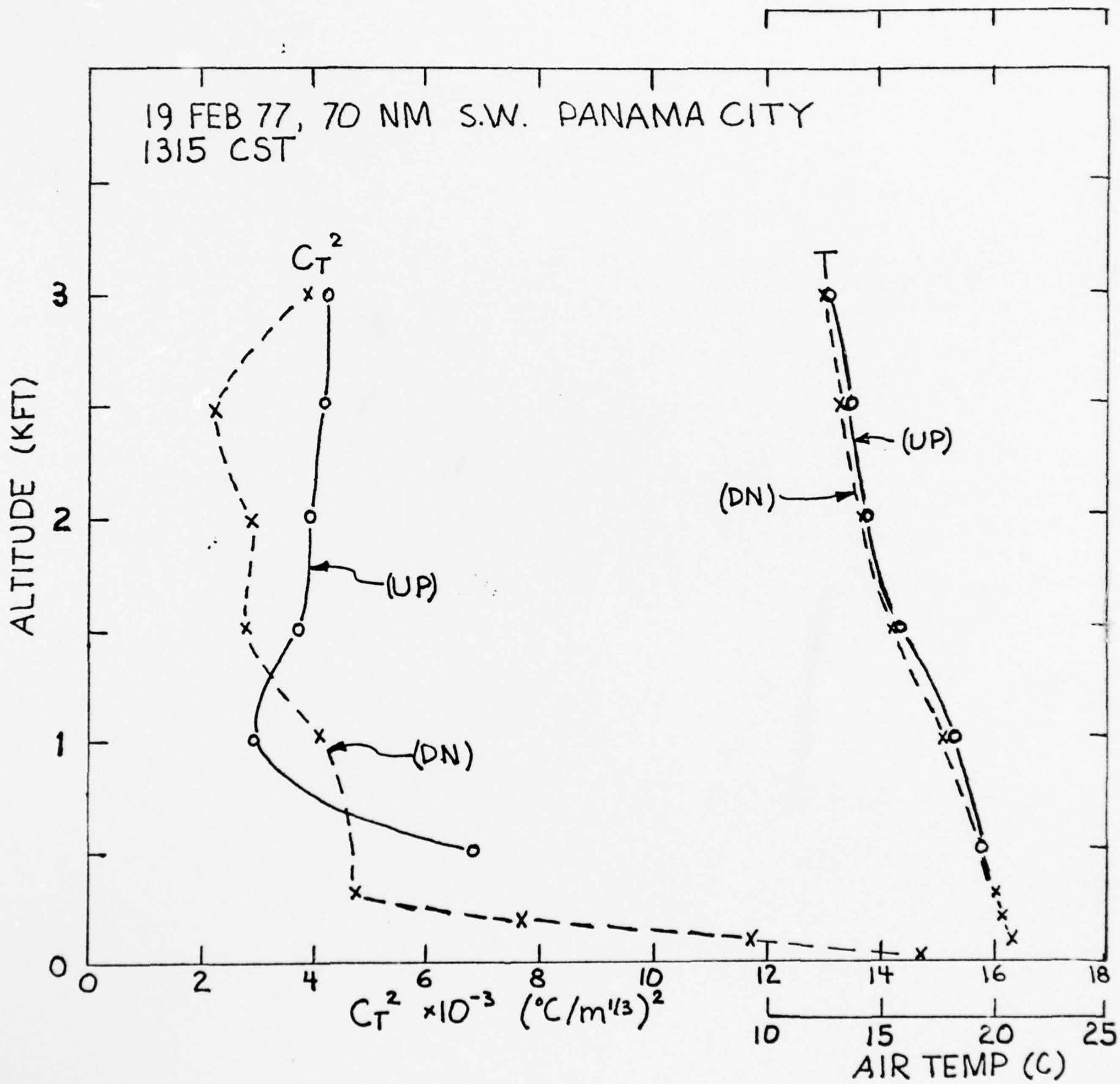


30 SEPT 76, 1608 PDST, SOUTH OF LONG BEACH
TD
SST
T
SOUNDING WITH BALLOON
VERY CLEAR
VIS 60+MILES
ALTITUDE (KFT)
0
1
2
3
4
5
6
7
8
9
10
11
-10
-5
0
5
10
15
20
25
T & TD (C)
19
20
21
22
23
SST (C)
15

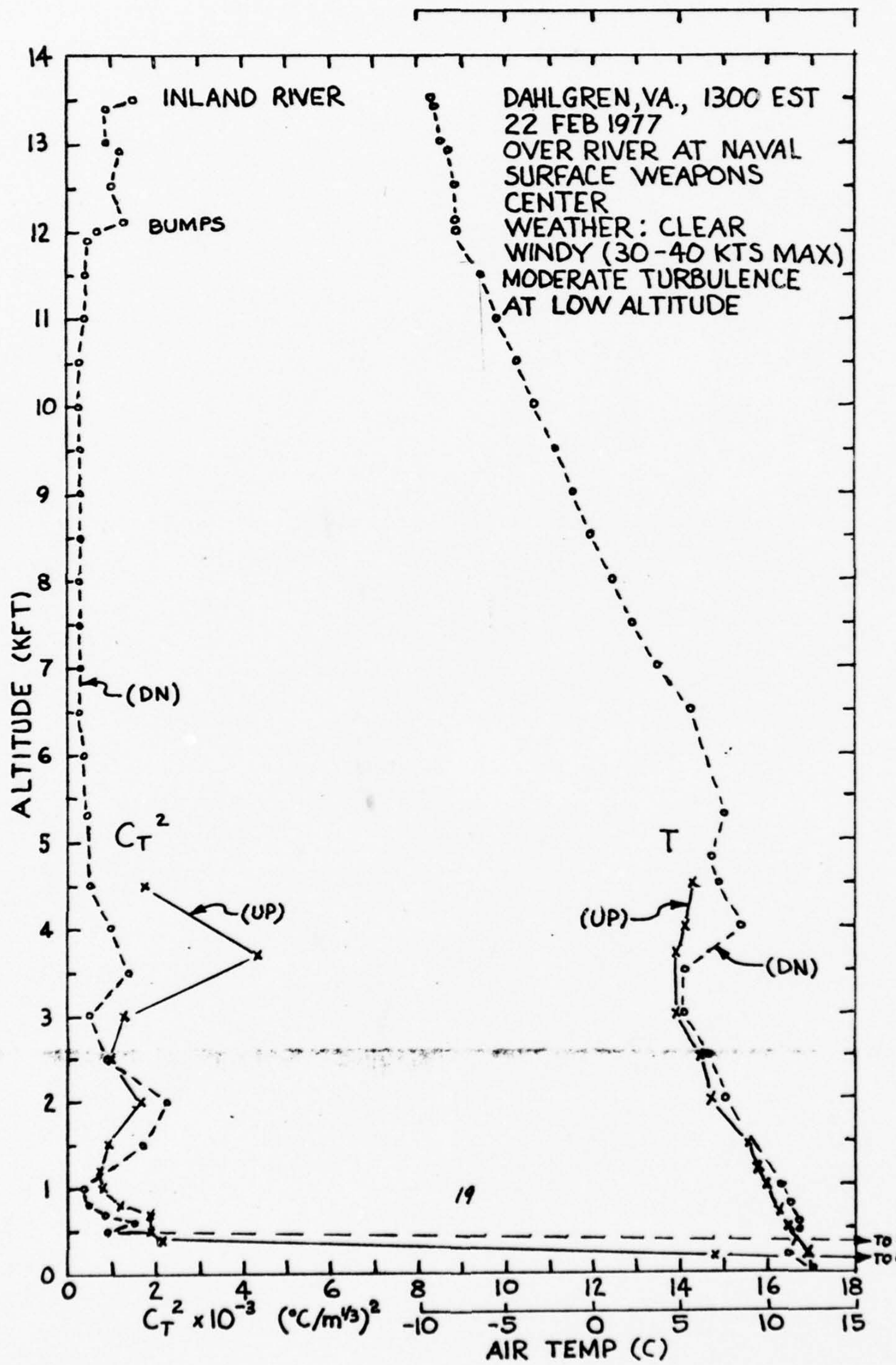


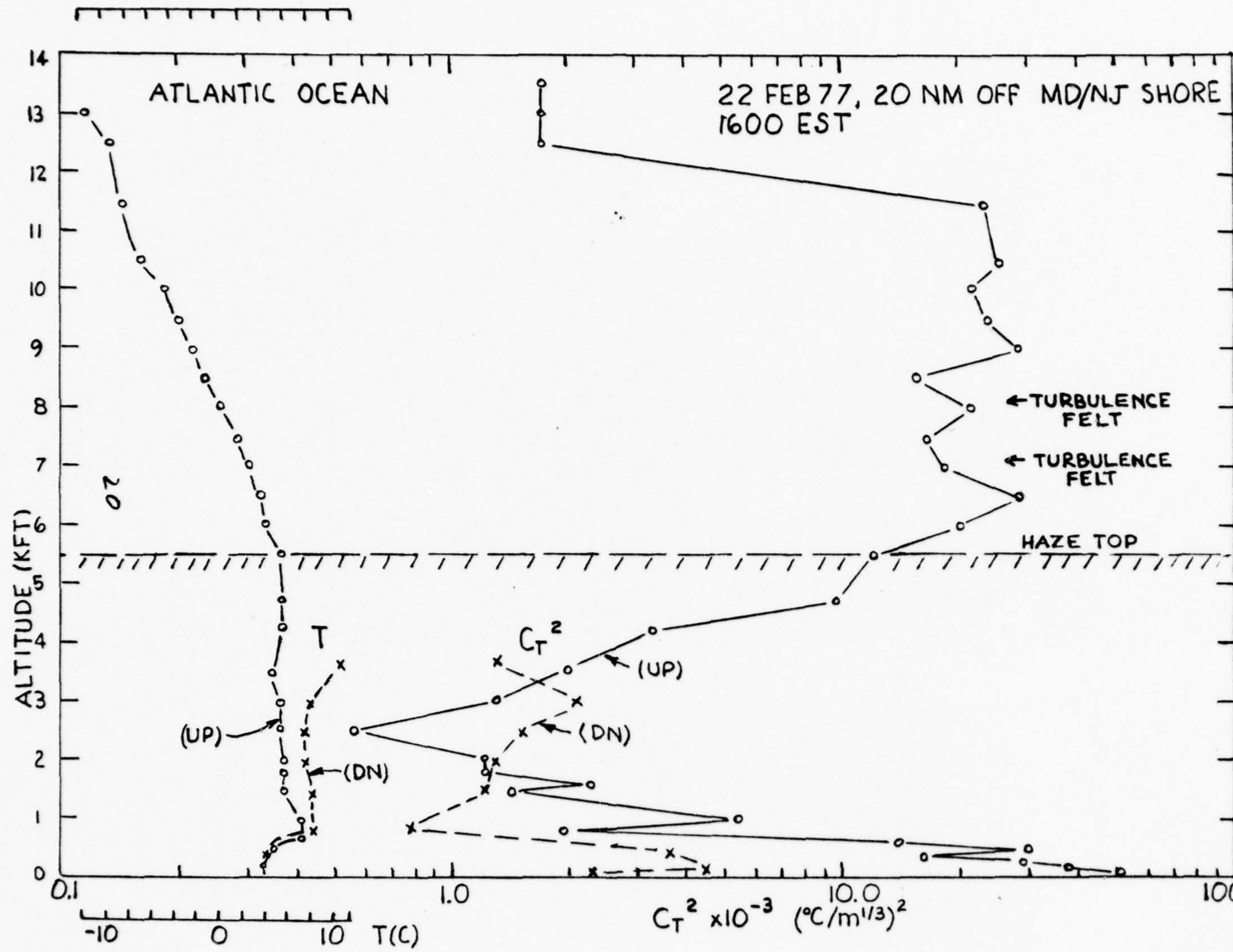
VARIATION OF C_T^2 WITH ALTITUDE


REFRACT (V)
0
0.1
0.2
0.3
0.4
REFRACTOMETER
C_T^2
SEA SFC TEMP
ALTITUDE (KFT)
30
25
20
15
10
5
0
GULF OF MEXICO
19 FEB 77, 1400 CST
SPIRAL AT POSITION OF FLA. QUEEN
10 NM SW OF STAGE I
NOTE: STAY WITHIN ABOUT 10 NM RADIUS OF SHIP'S POSITION
AIR TEMP
DEW PT
0
10
20
30
$C_T^2 \times 10^{-3}$ $(^oC/m^{1/3})^2$
14
15
16
17
18
19
SST (C)
-40
-30
-20
-10
0
10
20
30
T & T_D (C)



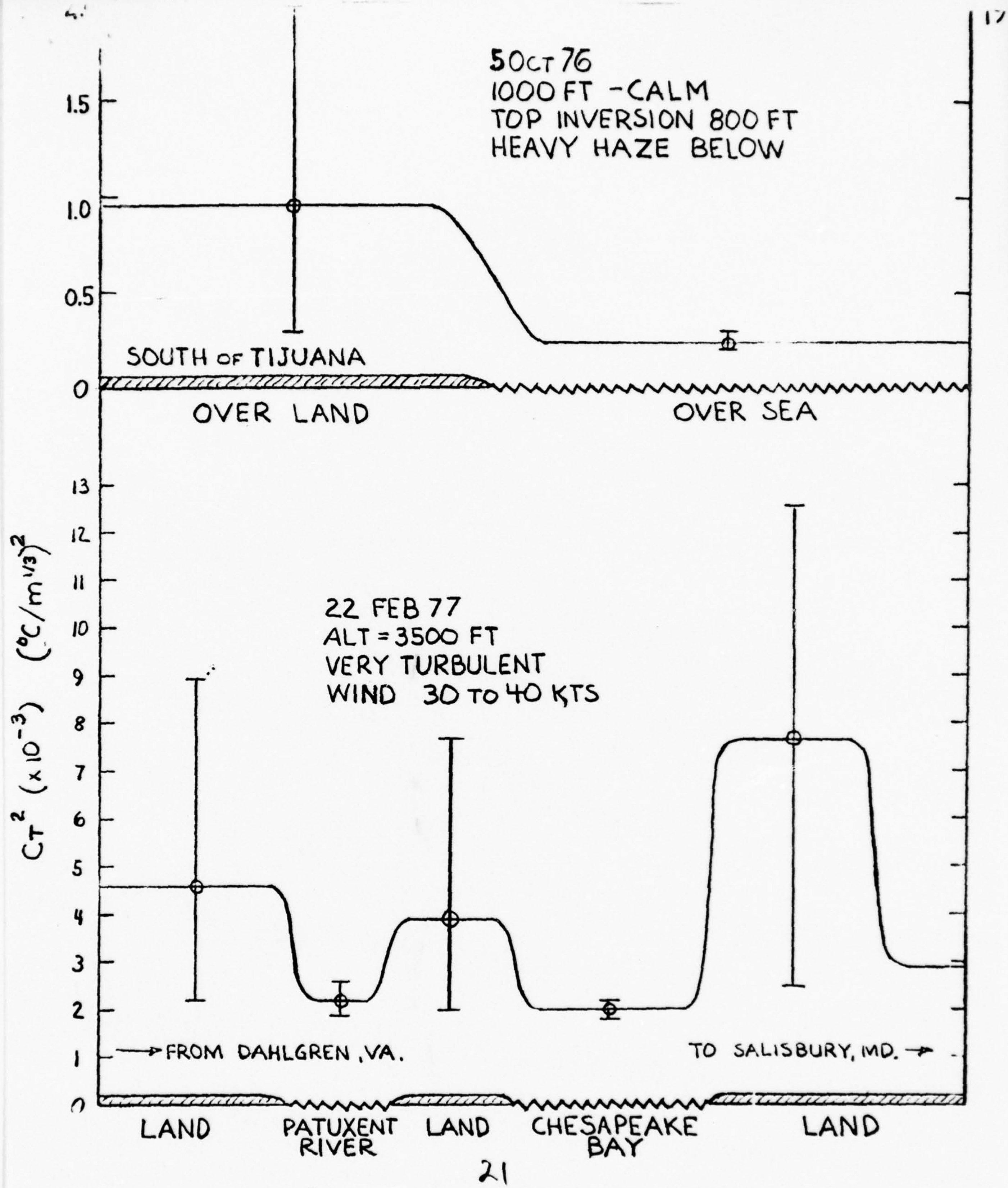
19 FEB 77, 70 NM S.W. PANAMA CITY
1315 CST
C_T^2
T
(UP)
(DN)
(UP)
(DN)
ALTITUDE (KFT)
0
1
2
3
0
2
4
6
8
10
12
14
16
18
$C_T^2 \times 10^{-3}$ $(°C/m^{1/3})^2$
10
15
20
25
AIR TEMP (C)


INLAND RIVER
DAHLGREN, VA., 1300 EST
22 FEB 1977
OVER RIVER AT NAVAL
SURFACE WEAPONS
CENTER
WEATHER: CLEAR
WINDY (30-40 KTS MAX)
MODERATE TURBULENCE
AT LOW ALTITUDE
BUMPS
(DN)
(UP)
C_T^2
T
TO 42
TO 42
19
ALTITUDE (KFT)
$C_T^2 \times 10^{-3}$ $(°C/m^{1/3})^2$
AIR TEMP (C)



ATLANTIC OCEAN
22 FEB 77, 20 NM OFF MD/NJ SHORE
1600 EST
TURBULENCE FELT
TURBULENCE FELT
HAZE TOP
T
(UP)
(DN)
C_T^2
(UP)
(DN)
ALTITUDE (KFT)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0.1
1.0
10.0
100
$C_T^2 \times 10^{-3}$ $(°C/m^{1/3})^2$
-10
0
10
T(C)

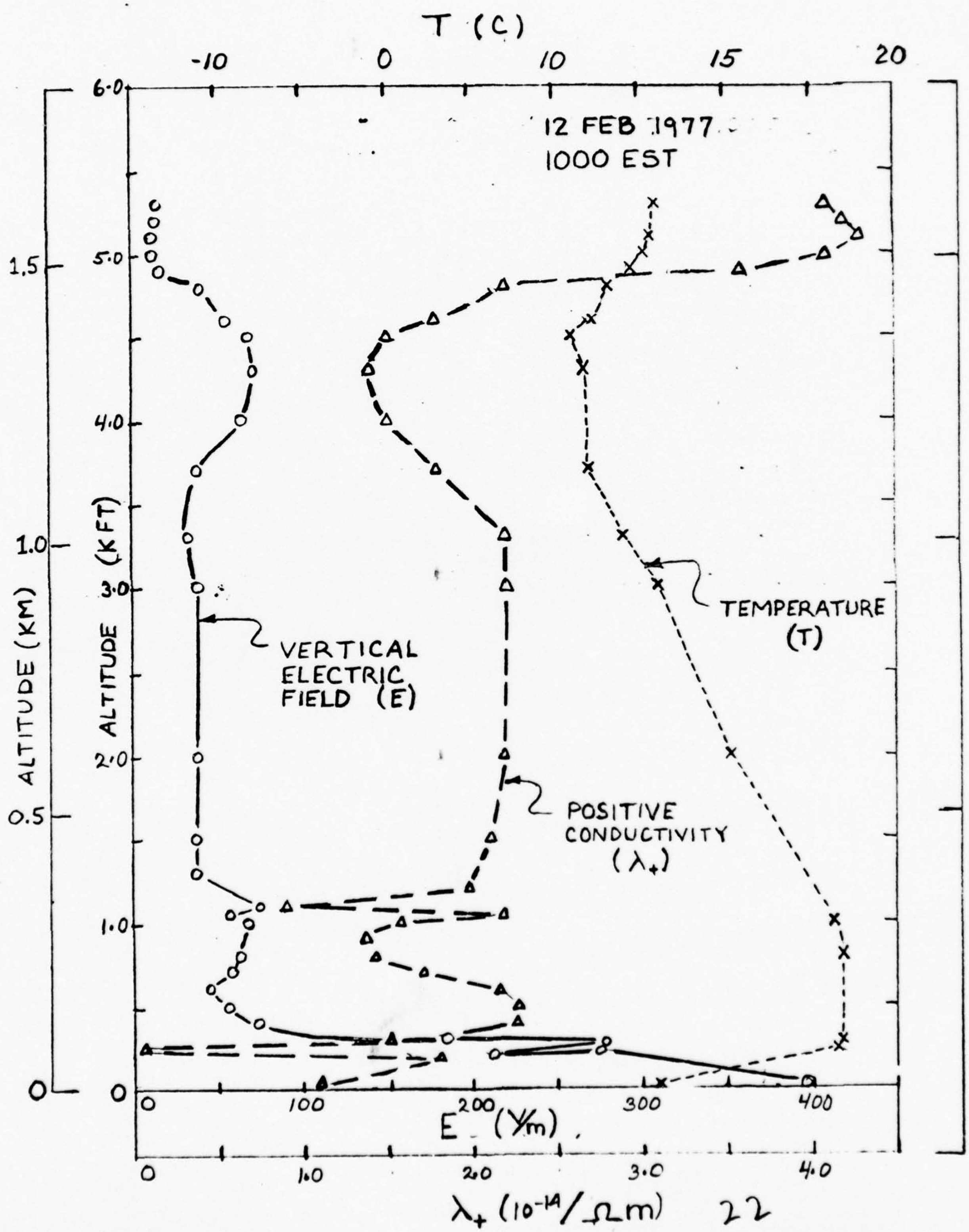
20



21

C_T^2 TURBULENCE VARIATION
LAND vs WATER

VERTICAL PROFILES OF ELECTRIC FIELD, CONDUCTIVITY AND TEMPERATURE OVER THE GULF OF MEXICO NEAR CLEARWATER, FLA.

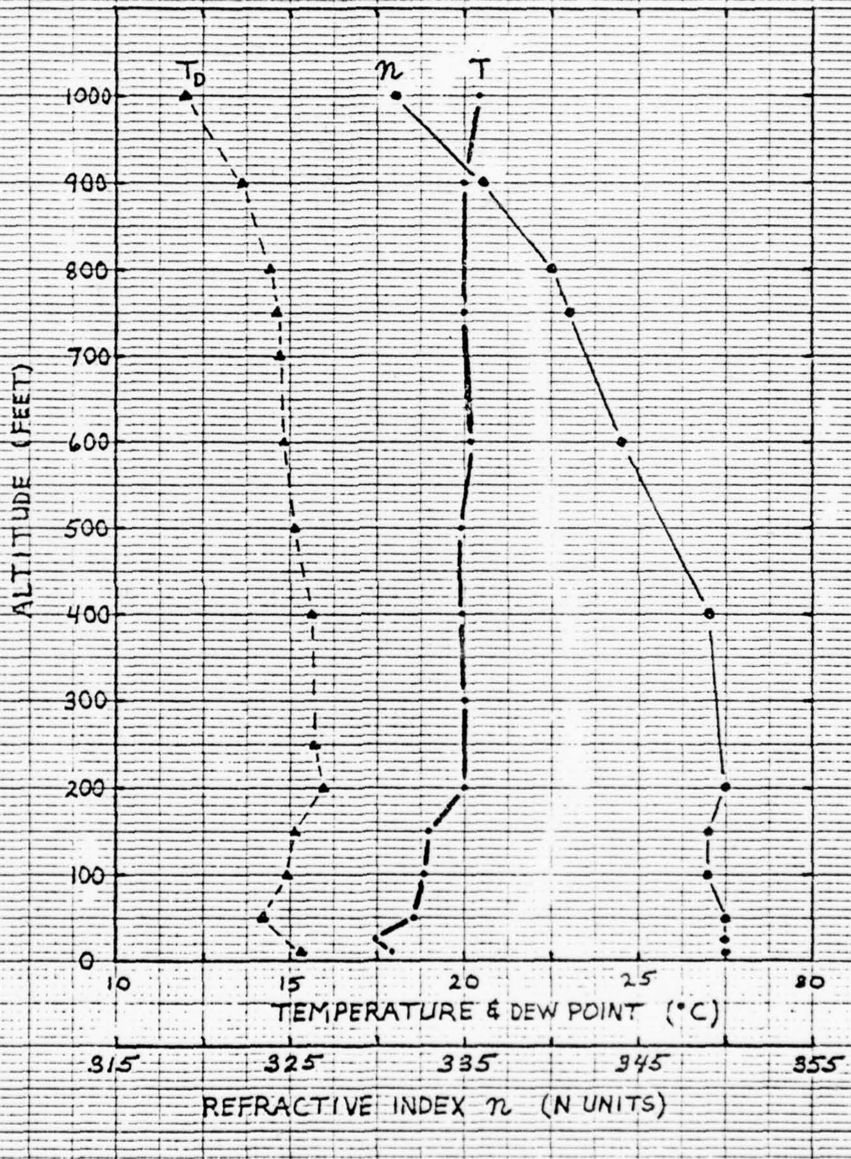


AIRBORNE RESEARCH ASSOCIATES
46 KENDAL COMMON ROAD • WESTON, MASSACHUSETTS 02193 • (617) 899-1834

1 JULY 1977

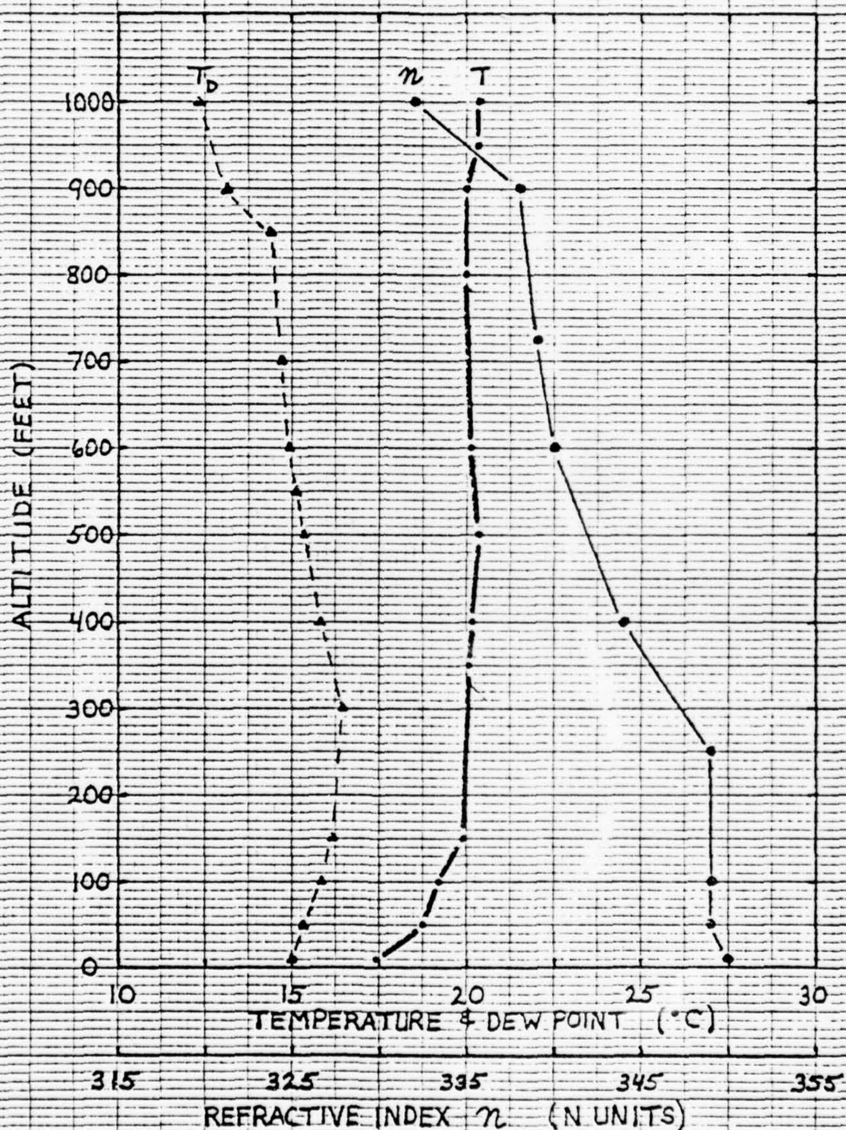
TEMPORAL VARIATION OF THE FINE STRUCTURE OF THE MARINE BOUNDARY LAYER (TEMPERATURE DEW POINT and REFRACTIVE INDEX) OFF NEW ENGLAND DURING JUNE 1977

A set of detailed soundings from 10 ft to 1000 ft above the ocean surface showing development of a strong inversion below 50 ft during the afternoon



DATE: 15 JUNE 1977 SPIRAL DESCENT OVER OCEAN
TIME: ~0910 EDT 7 MILES FROM HARBOR ENTRANCE
SEA LEVEL PRESSURE 30·03" PORTSMOUTH, NEW HAMPSHIRE

2/9

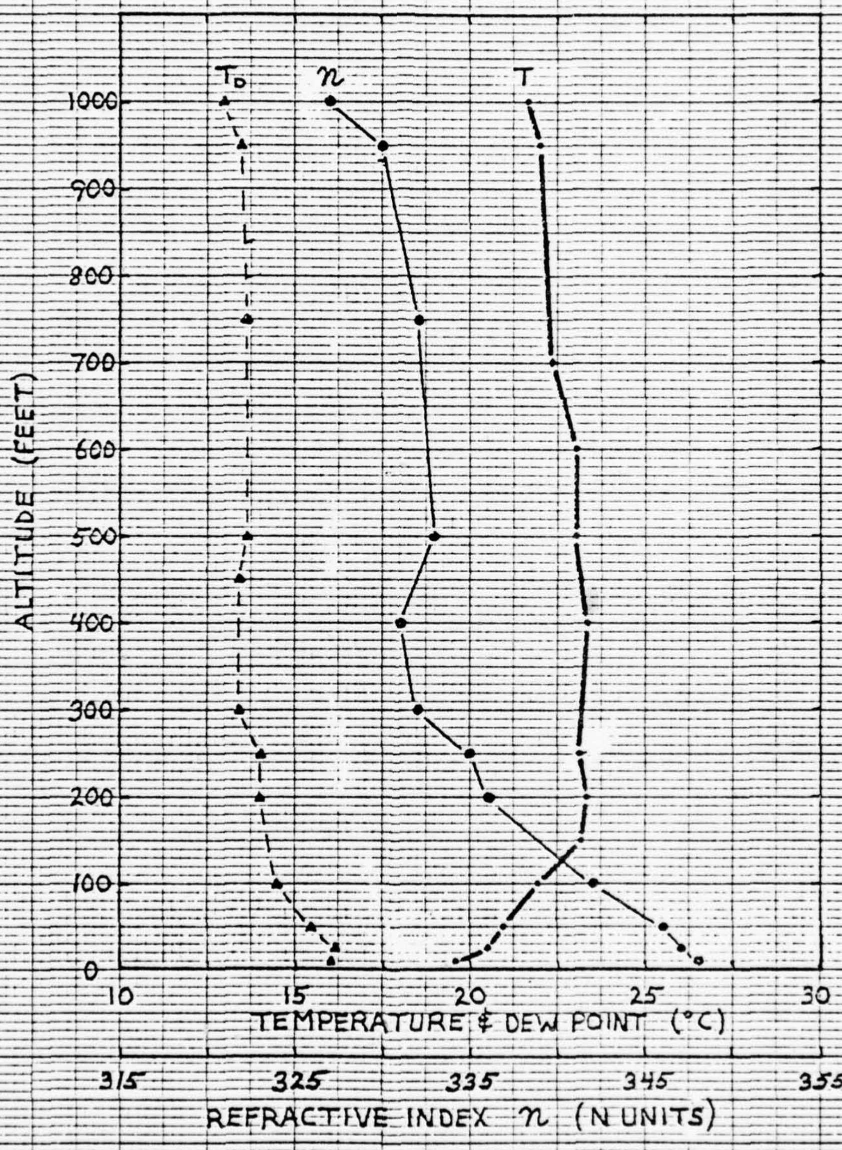


DATE: 15 JUNE 1977 SPIRAL ASCENT OVER OCEAN

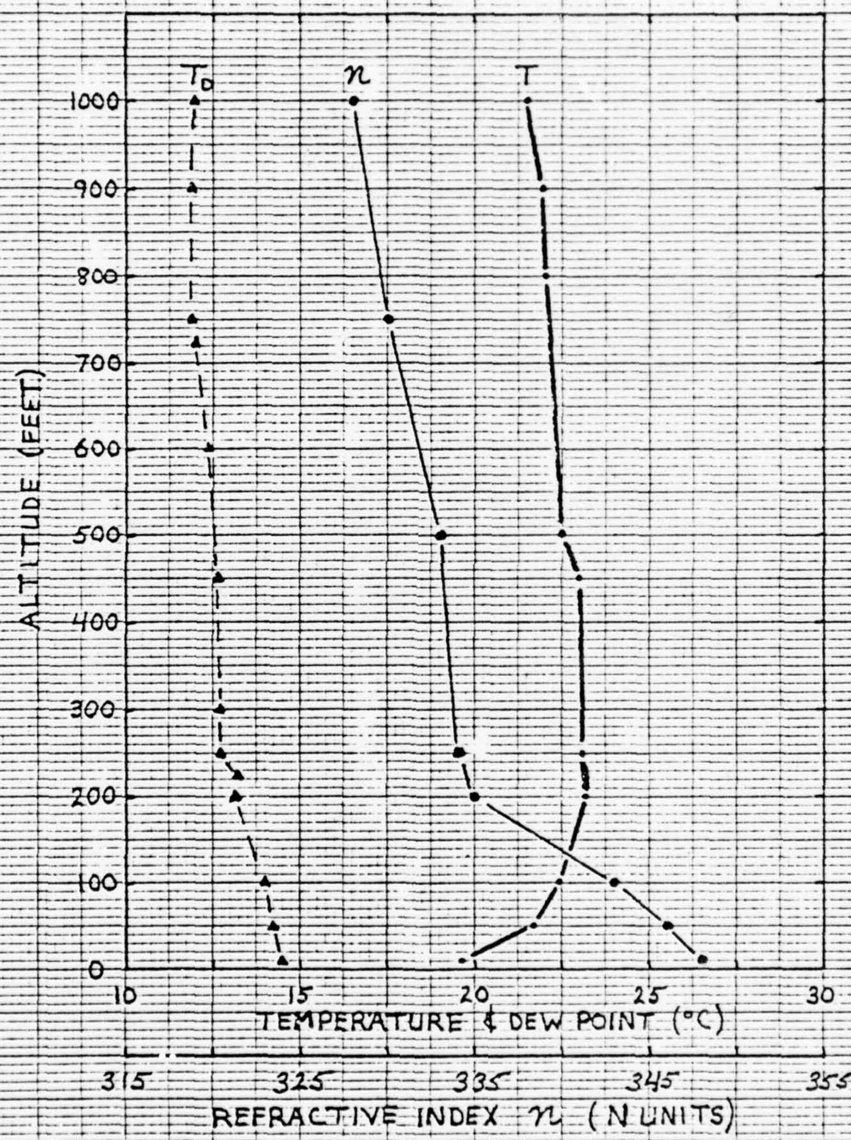
TIME: ~0915 EDT 7 MILES FROM HARBOR ENTRANCE

SEA LEVEL PRESSURE 30.03" PORTSMOUTH, NEW HAMPSHIRE

3/4



DATE: 15 JUNE 1977 SPIRAL DESCENT OVER OCEAN
TIME: ~1125 EDT 7 MILES FROM HARBOR ENTRANCE
SEA LEVEL PRESSURE PORTSMOUTH, NEW HAMPSHIRE
30.03"



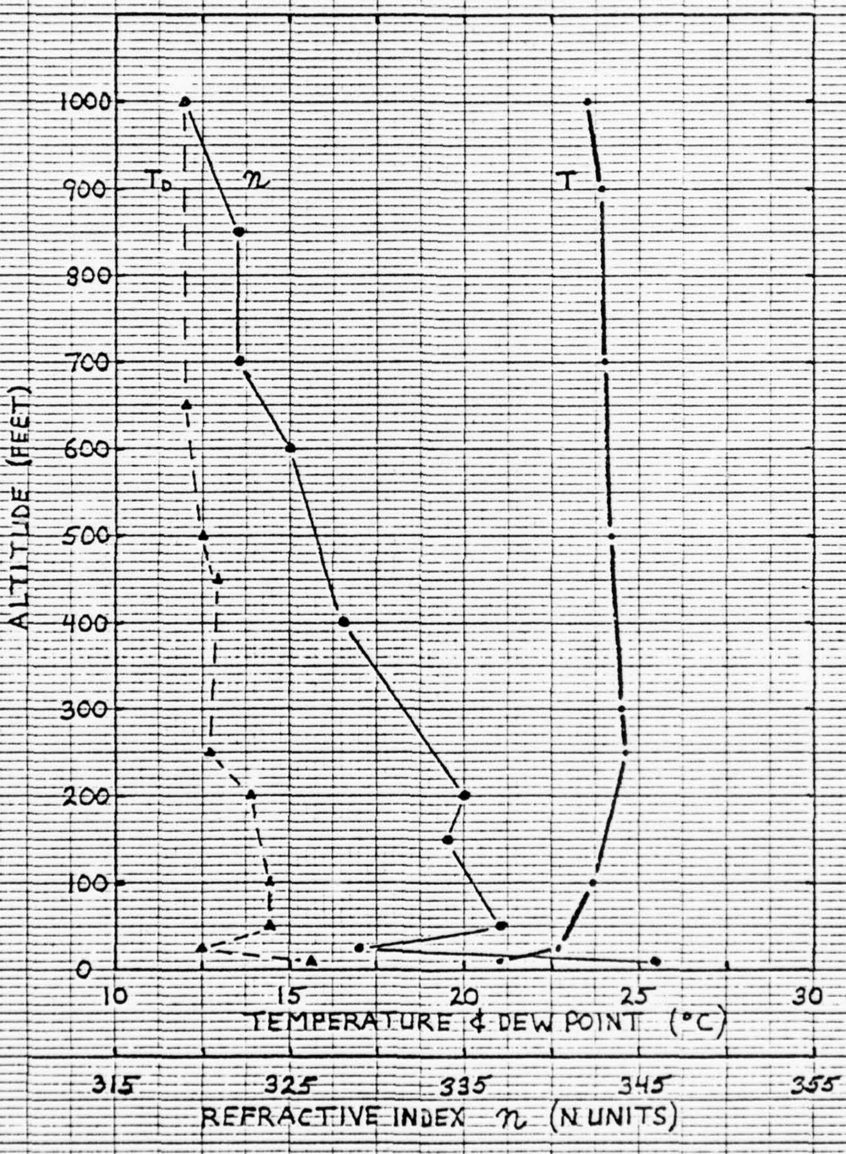
DATE: 15 JUNE 1977 SPIRAL ASCENT OVER OCEAN

TIME: ~1135 EDT 7 MILES FROM HARBOR ENTRANCE

SEA LEVEL PRESSURE PORTSMOUTH, NEW HAMPSHIRE

30.03"

5/9

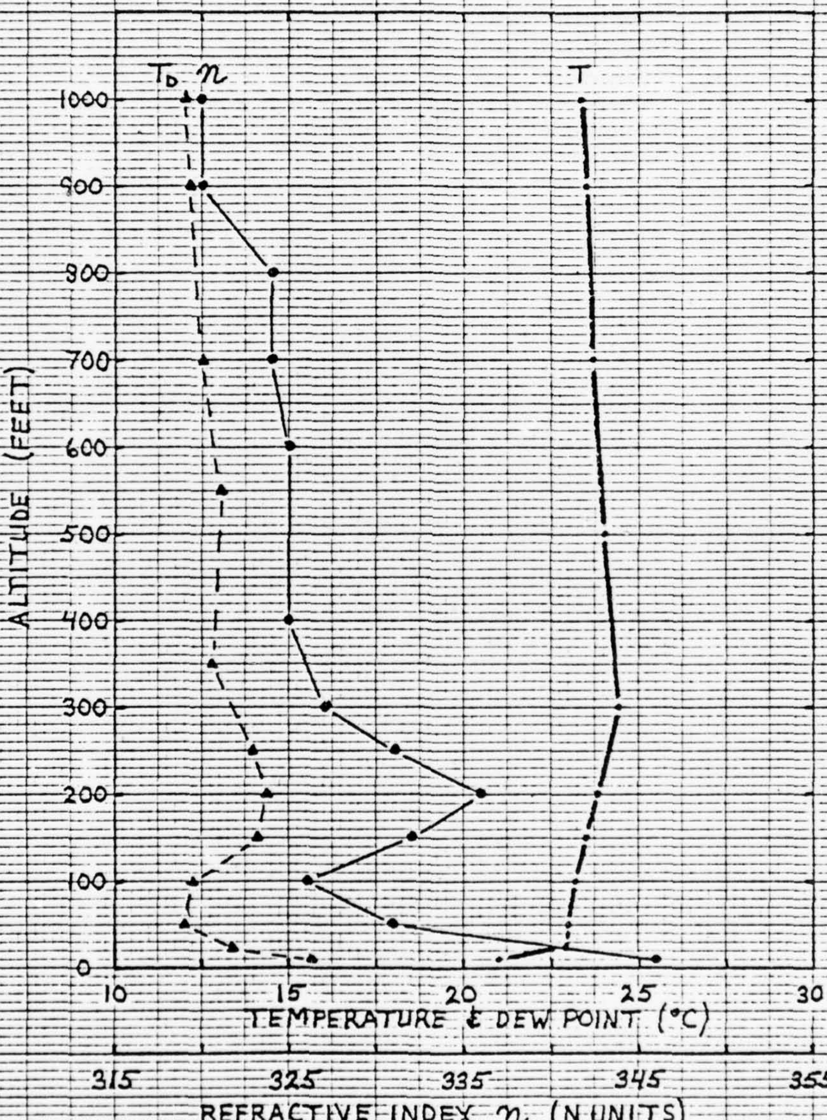


DATE: 15 JUNE 1977 SPIRAL DESCENT OVER OCEAN

TIME: ~1400 EDT 10 MILES FROM HARBOR ENTRANCE

SEA LEVEL PRESSURE 30.02" PORTSMOUTH, NEW HAMPSHIRE

6/9



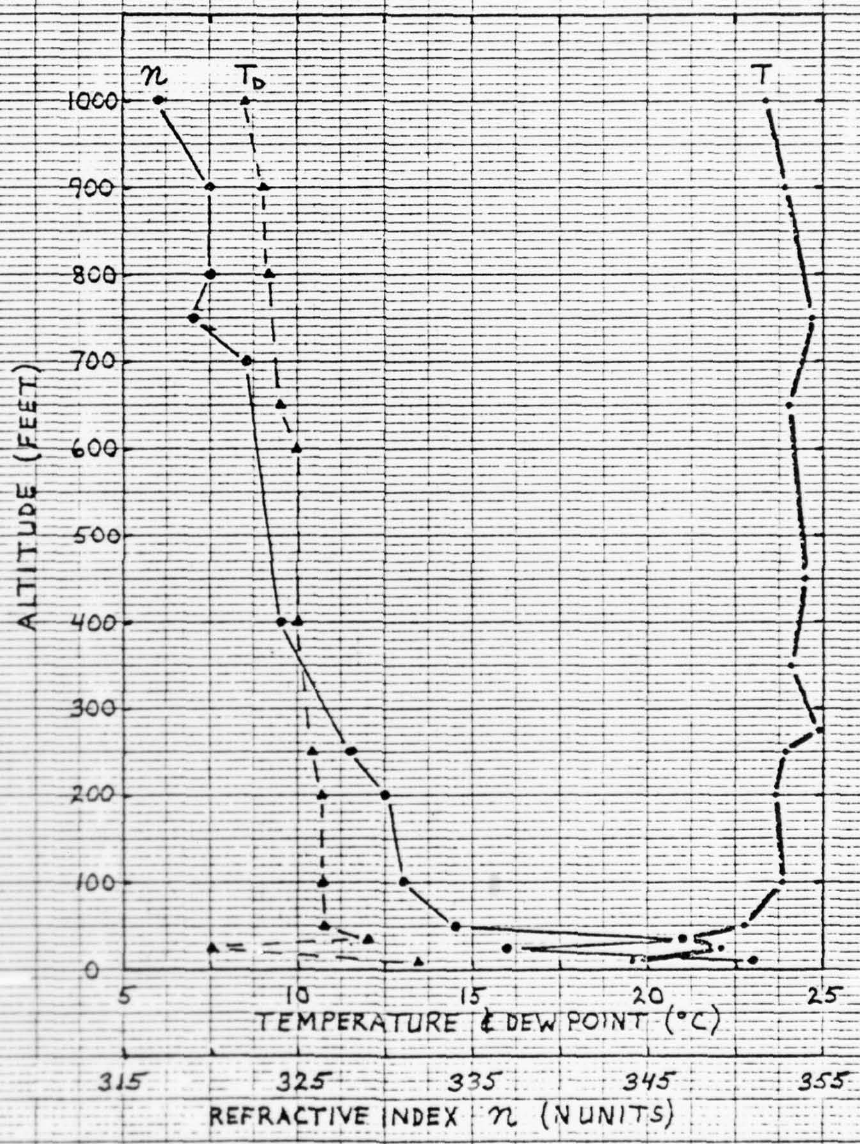
DATE: 15 JUNE 1977 SPIRAL ASCENT OVER OCEAN

TIME: 1405 EDT 10 MILES FROM HARBOR ENTRANCE

SEA LEVEL PRESSURE PORTSMOUTH, NEW HAMPSHIRE

30.02"

7/9



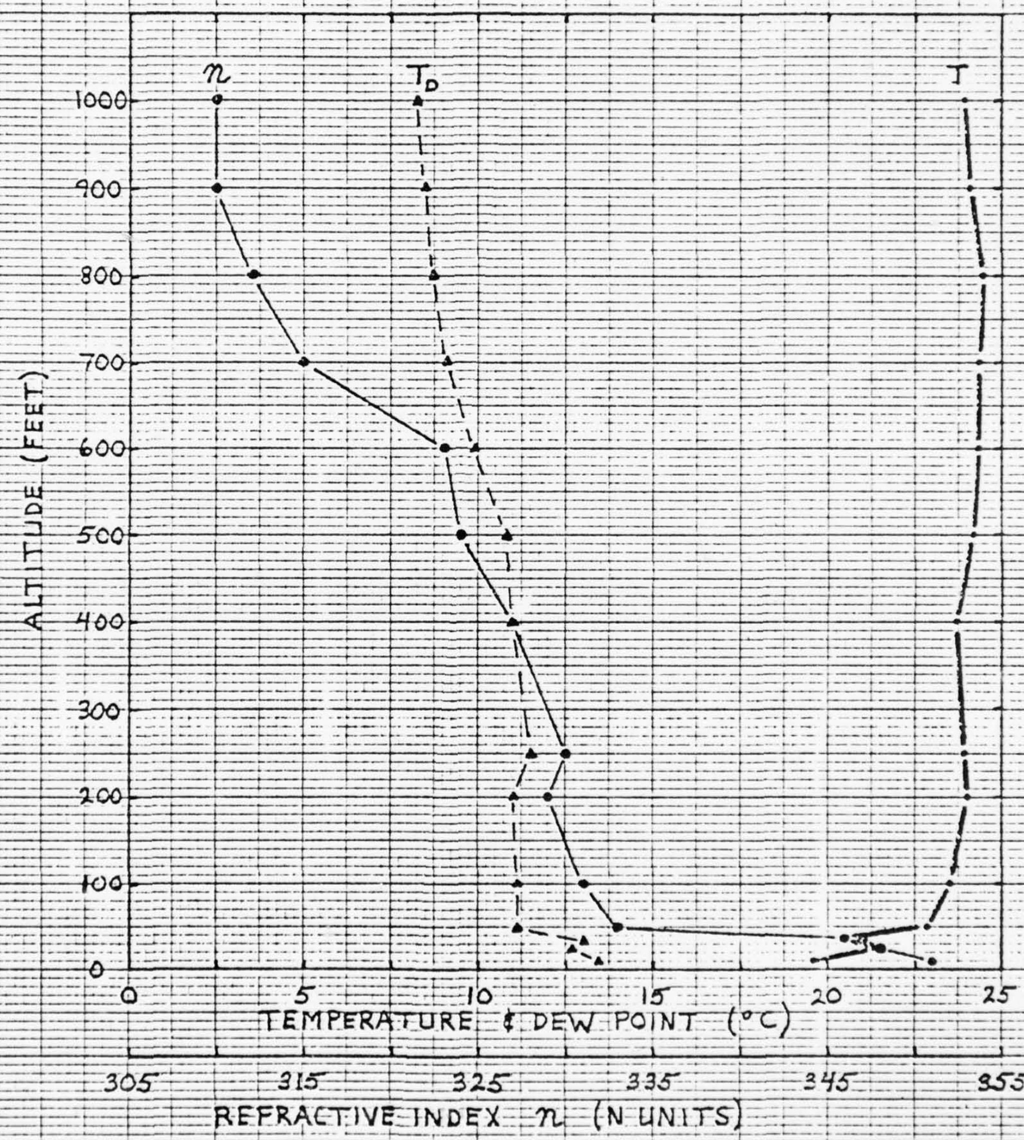
DATE: 15 JUNE 1977 SPIRAL DESCENT OVER OCEAN

TIME: ~1625 EDT 10 MILES FROM HARBOR ENTRANCE

SEA LEVEL PRESSURE PORTSMOUTH, NEW HAMPSHIRE

29.99"

8/9



DATE: 15 JUNE 1977 SPIRAL ASCENT OVER OCEAN
TIME: ~1630 EDT 10 MILES FROM HARBOR ENTRANCE
SEA LEVEL PRESSURE PORTSMOUTH, NEW HAMPSHIRE
29.99"

9/9

AIRBORNE RESEARCH ASSOCIATES
46 KENDAL COMMON ROAD • WESTON, MASSACHUSETTS 02193 • (617) 899-1834

8 August 1977

ATMOSPHERIC STRUCTURE OVER THE TEST RANGE AT THE NAVAL SURFACE WEAPONS CENTER, DAHLGREN, VIRGINIA

INTRODUCTION

This report describes variations in temperature turbulence (C_t), dew-point (T_d) and temperature (T) as a function of altitude and position over the Naval Surface Weapons Center test range over the Potomac River at Dahlgren, Virginia. These measurements were made during the week of 18 April 1977 as part of an infra-red imaging test program being conducted at Dahlgren for the Naval Sea Systems Command High Energy Laser Program (Lt. M.M. Hughes). Airborne Research Associates was supported in this investigation through funds transferred to its Naval Air Systems Command Contract N00019-76-C-0588 (M.H. Schefer, AIR 370/C, Project Monitor).

Since atmospheric turbulence and humidity strongly influence electro-optical sensing, it was desired to characterize the structure of the atmosphere relative to these parameters along flight paths taken by jet aircraft being observed with infra-red imaging during the tests. In addition, the Bellanca meteorological research aircraft itself served as a target while making the measurements.

The planned flight paths for the jet aircraft were 3°, 10° and 20° dives at the e-o sensors which were located at the shore line at the north end of the test range. The dives started about 6 nautical miles downrange over the center of the river. During an interval of approximately 45 minutes immediately before and after the jet aircraft made its runs, the Bellanca made dives over the same flight paths terminating at an altitude of 50 to 100 ft above the ground over the sensors. Because the 20° dives proved too steep for the Bellanca (excessive air speed) these dives were changed to a 15° angle and the jet aircraft's flight paths modified accordingly. In addition to the constant angle dive measurements, vertical spiral soundings were made just downrange from the sensors (1/2 to 1 mile) and at the far end of the flight paths (6 miles). We also made constant altitude measurements

from the sensors out to the 6 mile point. The vertical soundings and constant level runs were conducted in order to better define the significant differences in air mass structure along the test range; one end was at a land/water interface while the other was over the center of a 4-mile wide river. It would be expected (and our previous measurements have shown) that C_t varies typically by an order of magnitude between a heated land surface compared to over water.

This report contains 28 graphs depicting the variation of parameters on individual runs as a function of altitude and distance from the infra-red sensors. These data are also given in tabular form for easier use during analysis. Not every desired measurement was obtained because of breakage of the 2 1/2 micron C_t sensing wires. The wires used during the Dahlgren tests apparently came from a bad batch supplied by the manufacturer. The sensors were located at the aircraft's wingtip on a 2/3 meter high vertical mast with two at the top and two at the bottom. As long as there was one good one on top and one on the bottom it was possible to change inputs to the electronics in the cockpit and continue the measurements. However, when both wires on one side broke, C_t could no longer be measured. For this reason some of the records only show dew-point and temperature.

We wish to acknowledge the close cooperation of Drs. Chris Fairall and Ken Davidson of the Naval Postgraduate School, Monterey, who have supplied the C_t instrumentation used on our aircraft. Chris came to Dahlgren to participate in the measurements. This work is part of an ongoing program to develop improved capability to measure atmospheric turbulence that is being conducted by Airborne Research Associates in conjunction with the PGS group as part of the Naval Air Systems Command Marine Fog Program. In the future we expect to develop the capability for obtaining airborne measurements of ϵ , the velocity turbulence structure function, and we may operate a Knollenberg aerosol spectrometer. These parameters will completely define the atmospheric mixed layer for purposes of electro-optical studies.

TEMPERATURE STRUCTURE FACTOR

I. Given two separate temperature sensors 1 and 2 a distance d apart, the temperature structure factor C_T^2 is defined by

$$C_T^2 = \overline{(T_2 - T_1)^2}\, d^{-2/3} \qquad \overline{} \text{ denotes average} \tag{1}$$

This is related to the Kolmogorov spectrum of temperature fluctuations by

$$\Phi_T(k) = \beta C_T^2 k^{-5/3} \tag{2}$$

$\beta = .25$

k = wave number of fluctuation

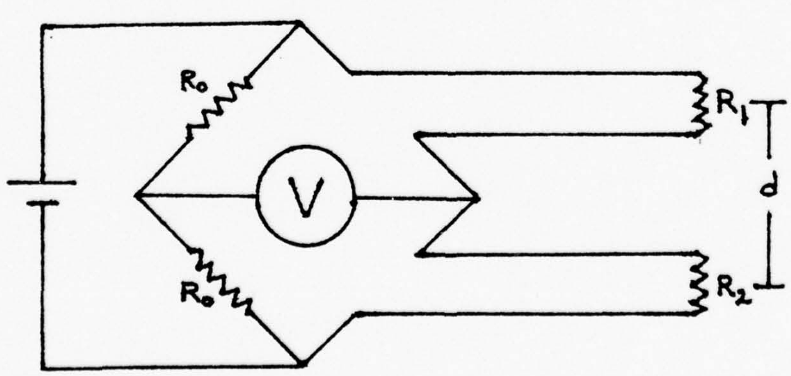
The refractive index structure factor C_N^2 is related to C_T^2 by*

$$C_N^2 = (79\times10^{-6}\, P/T^2)^2\, C_T^2 \tag{3}$$

P = pressure in mb

T = temperature in K

The device we have used to measure C_T^2 is a DC wheatstone bridge (Thermo - Systems Inc., model 1044) that senses the relative resistance fluctuations of a pair of 2.5 micron platinum wires (micro-thermal sensors) separated a distance d.



* Assumes no humidity fluctuations

The voltage output of the bridge, V, is related to the resistance change through the quantity G by

$$G = dV/dR \ , \quad \text{volts/ohm} \qquad G \sim 1\ v/\Omega$$

The resistance change produced by a temperature change is related to the temperature coefficient of platinum, α , by

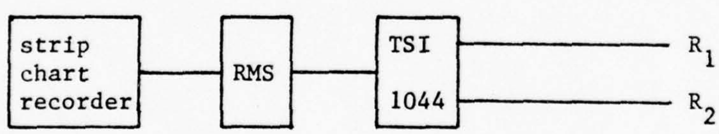
$$dR/dT = R\alpha, \quad R = \text{wire resistance}$$
$$\text{where} \quad R \sim 50\,\Omega \ \text{and} \ \alpha = .0036\ K^{-1}$$

C_T^2 is related to the RMS of the voltage fluctuations by

$$C_T^2 = \frac{1}{(\alpha G R)^2\, d^{2/3}} \left(V_{rms} \right)^2 , \quad K^2 m^{-2/3} \tag{4}$$

II. Aircraft Operation

We have mounted paired micro-thermal sensors on the wingtip of the airplane. Cables run through the wing and connect to a TSI 1044 bridge, the output of the bridge is connected to an RMS meter (τ= 2.5 sec.) and monitored with a strip chart recorder.



III. Refractive Index

Calculation of C_N^2 from C_T^2 is done with equation (3). If we rewrite equation (3) as

$$C_N^2 = F\ C_T^2 \tag{5}$$

then we can calculate F as a function of altitude for the <u>Standard Atmosphere</u>.

$$C_N^2 = \left(7.9\text{x}10^{-5}\ \frac{P}{T^2}\right)^2 C_T^2 = F\ C_T^2 \qquad 5 \tag{6}$$

Table I. STANDARD ATMOSPHERE

Altitude (kft)	Pressure (atm.)	T(K)	F ($\times 10^{-13}$)
0	1.0	288	9.1
1.0	.96	286	8.6
2.0	.93	284	8.3
3.0	.90	282	8.0
4.0	.86	280	7.5
5.0	.83	278	7.2
6.0	.80	276	6.9
7.0	.77	274	6.6
8.0	.74	272	6.2
10.0	.69	268	5.8
15.0	.56	259	4.3
20.0	.46	248	3.5
30.0	.30	229	2.0

IV. Data Evaluation

The most important consideration in the accuracy of the data is the noise level of the system. There are two sources of noise :

1. Broadband noise in the bridge circuit, under laboratory conditions this noise is about .5mv rms, which corrsponds to $C_T^2 \sim 10^{-5}\ K^2 m^{-2/3}$ or at sea level, $C_N^2 \sim 10^{-17}\ m^{-2/3}$.

2. Under flight conditions we observe larger noise levels, presumably due to ignition pickup in the power supply or directly in the electronics. In this case the noise level is about 1.6mv which corrsponds to $C_T^2 \sim 10^{-4}\ K^2 m^{-2/3}$ or $C_N^2 \sim 10^{-16}\ m^{-2/3}$.

It is possible to improve the accuracy by correcting for the noise. If we assume

$$V_T = V + V_N$$

$$\overline{V_T^2} = \overline{V^2} + \overline{V_N^2} + \overline{2VV_N}$$

if V_N is randomly correlated with V then $\overline{VV_N} = 0$.

6

Then we have

$$\overline{V_T^2} = \overline{V^2} + \overline{V_N^2}$$

and

$$\overline{V^2} = \overline{V_T^2} - \overline{V_N^2}$$

So that the V_{rms} that we use in equation (4) would be

$$V_{rms} = \sqrt{V_T^2 - V_N^2}$$

where V_T is the actual measured rms voltage and V_N is the noise. However, we must bear in mind that at $C_N^2 \sim 10^{-16}\ m^{-2/3}$ our signal to noise ratio is on the order of 1.

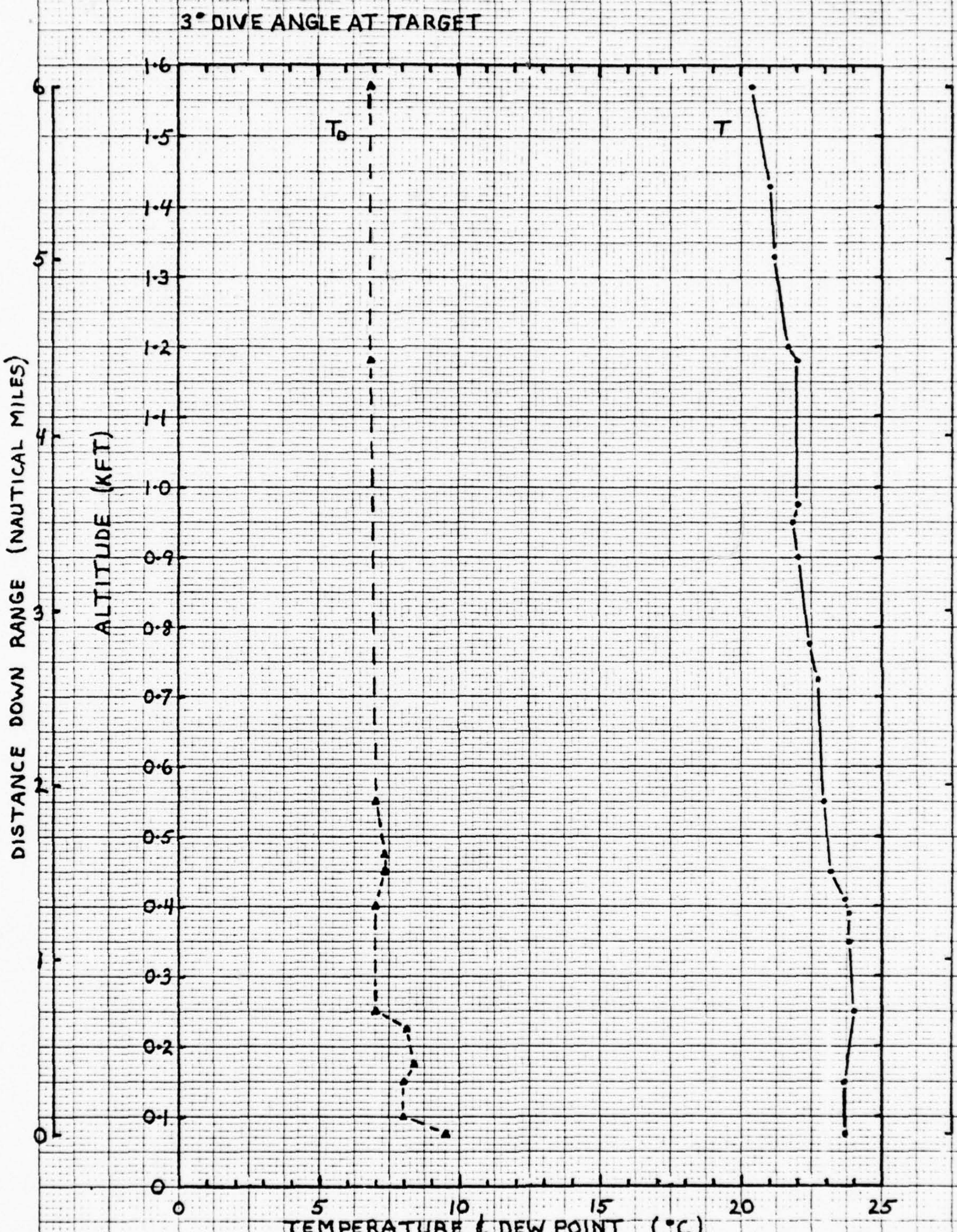
V. Comments about the Temperature Structure Factor

There have been some measurements of C_T^2 (or C_N^2) from airplanes and balloons. In addition, a number of surface measurements have been made which have lead to the developement of a boundary layer model of C_T^2 height dependence, valid up to near the lowest inversion. The airplane and balloon measurements have shown several things

1. The height dependence of C_T^2 can differ radically depending on the atmospheric stability, layering etc.

2. C_T^2 exhibits order of magnitude increases at inversions or other air mass boundaries. These have been observed as high as 15,000 feet.

The near surface boundary layer model is based on the idea that turbulence is produced by two methods - convection and wind shear. In the boundary layer, the wind shear is due to friction with the surface. The height dependence of C_T^2 is based on the competition of these two mechanisms as expressed in terms of the stability of the surface layer. As a result, in stable, neutral or slightly unstable regimes, $C_T^2 \sim Z^{-2/3}$. In very unstable (convective) conditions, $C_T^2 \sim Z^{-4/3}$.

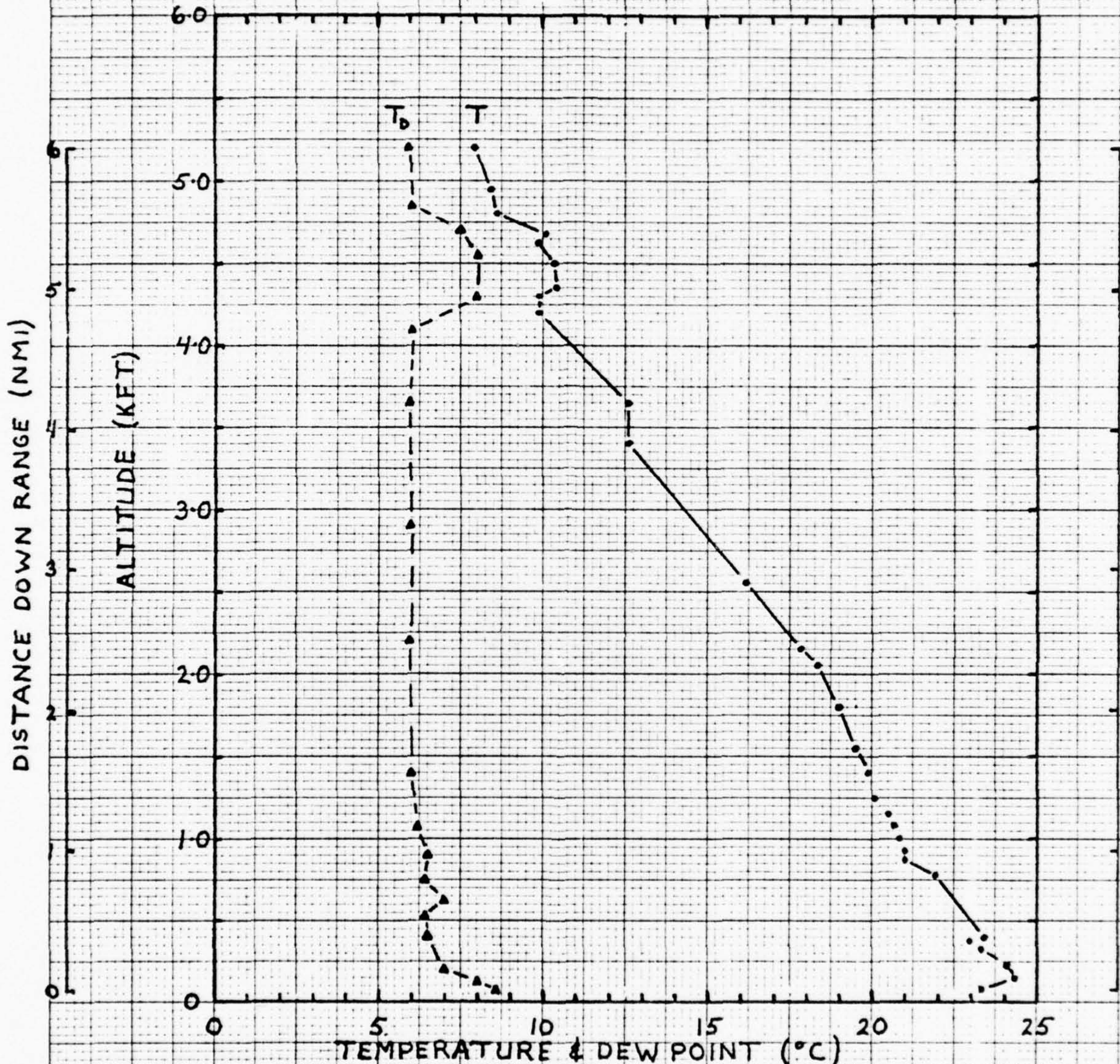


DAHLGREN, VA NSWC TEST RANGE
18 APRIL 1977 1235 EST 3° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
18 April 1977 1235 EST 3° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.075	23.7	9.5
	.100		8.0
	.150	23.7	8.0
	.175		8.3
	.225		8.1
	.250	24.0	7.0
	.350	23.8	
	.390	23.8	
	.400		7.0
	.410	23.7	
	.450	23.2	7.3
	.475		7.3
	.550	22.9	7.0
	.725	22.7	
	.775	22.4	
	.900	22.0	
	.950	21.8	
	.975	22.0	
	1.18	22.0	6.8
	1.2	21.7	
	1.33	21.2	
	1.43	21.0	
6	1.57	20.3	6.8

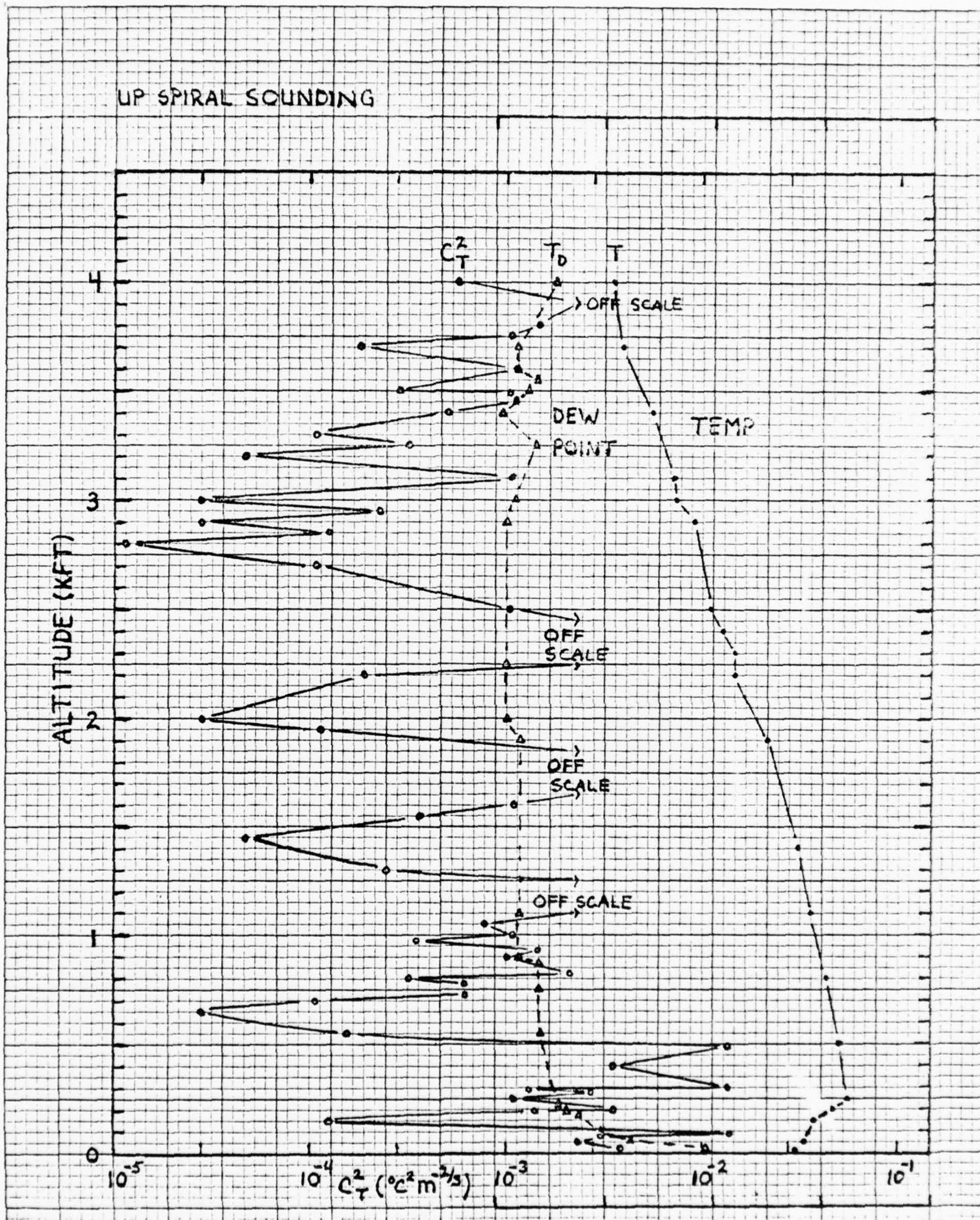
10° DIVE ANGLE AT TARGET



DAHLGREN, VA NSWC TEST RANGE
18 APRIL 1977 1245 EST 10° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
18 April 1977 1245 EST 10° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.075	23.3	8.6
	.125	24.2	8.0
	.150	24.3	
	.200		7.0
	.225	24.1	
	.300	23.7	
	.325	23.3	
	.375	23.0	
	.400	23.4	6.5
	.525		6.4
	.625		7.0
	.750		6.4
	.775	21.9	
	.790	21.5	
	.850	21.3	
	.875	21.0	
	.900		6.5
	.925	21.0	
	.950	20.9	
	1.0	20.8	
	1.08	20.7	6.2
	1.15	20.5	
	1.25	20.1	
	1.4	19.9	6.0
	1.55	19.5	
	1.8	19.0	
	2.05	18.3	
	2.15	17.8	
	2.2		5.9
	2.55	16.2	
	2.9		5.9
	3.4	12.6	
	3.65	12.6	5.9
	4.1		6.0
	4.2	9.9	
	4.3	9.9	8.0
	4.35	10.4	
	4.5	10.3	
	4.55		8.0
	4.63	9.9	
	4.68	10.1	
	4.7		7.5
	4.8	8.6	
	4.85		
	4.95	8.4	
6	5.2	7.9	5.9



DAHLGREN, VA NSWC TEST RANGE
18 APRIL 1977 1120 EST UP SPIRAL SOUNDING
3 NAUTICAL MILES DOWN RANGE FROM TARGET SITE

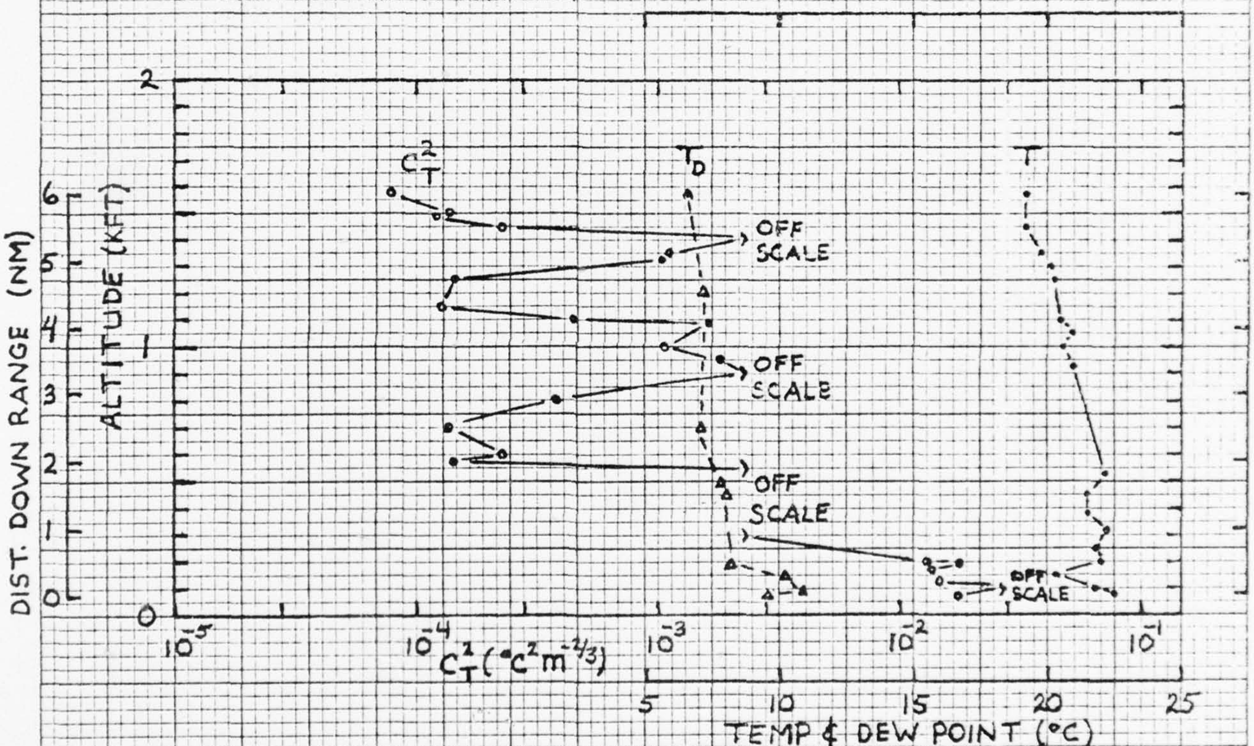
Dahlgren, VA NSWC Test Range
18 April 1977 1120 EST Up Spiral Sounding
3 NM Down Range From Target Site

Altitude (kft)	$C_T^2 \times 10^{-3}$ ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
.010	6.26	18.7	14.6
.050	4.31	19.2	
.060	5.74		11.2
.075	3.21		
.090	23.4		9.9
.150	.19	19.6	
.190	2.26		8.8
.200	5.9	20.5	8.3
.220			7.9
.250	1.3	21.2	
.275	4.92		
.290	2.10		
.300	21.6		
.400	5.91		
.490	22.0		
.500		20.8	
.550	.27		7.1
.650	.05		
.700	.13		
.725	.81		
.750			7.0
.775	.81		
.800	.55	20.2	
.825	3.88		
.875			7.0
.900	1.0		6.1
.925	2.44		
.975	.58		
1.0	1.26		
1.05	.85		
1.1	off scale	19.5	6.1
1.25	at 4.3		
1.3	.45		
1.4		18.9	
1.45	.07		
1.55	.55		
1.6	1.31		
1.65	off scale		
1.85	at 4.3		
1.9		17.5	6.1
1.95	.15		
2.0	.05		5.5
2.2	.35	16.0	
2.25			
2.3	off scale at 4.3	16.0	
2.4		15.4	
2.5	1.12	14.9	5.5
2.7	.13		

Dahlgren, VA NSWC Test Range
18 April 1977 1120 EST Up Spiral Sounding

Altitude (kft)	$C_T^2 \times 10^{-3}$ ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
2.8	.015		
2.85	.19		
2.9	.05	14.1	5.5
2.95	.42		
3.0	.05	13.3	5.9
3.1	1.17	13.2	
3.2	.07		
3.25	.55		6.8
3.3	.13		
3.4	.73	12.2	5.3
3.45	1.42		
3.5	.51		6.5
3.55			6.8
3.6	1.42		6.0
3.7	.33	10.8	6.0
3.75	1.21		
3.8	2.44		
3.9	off scale at 4.3		
4.0	.77	10.4	7.7

3° DIVE ANGLE AT TARGET

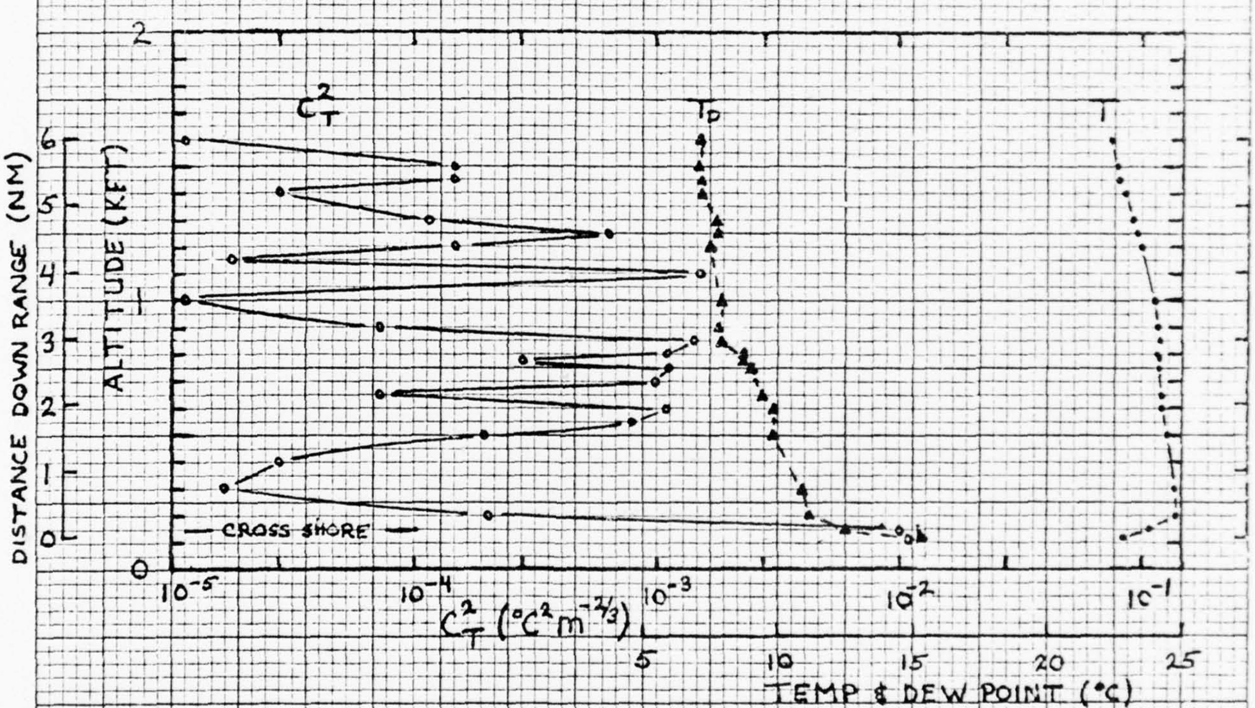


DAHLGREN, VA NSWC TEST RANGE
18 APRIL 1977 1135 EST 3° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
18 April 1977 1135 EST 3°Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} ($°C^2m^{-2/3}$)	T(C)	T_D(C)
0	.075	31.4	22.5	9.6
	.090	off scale at 49.2	20.9	10.8
	.100	49.2	21.8	9.6
	.125	24.0		
	.150		20.4	10.2
	.175	22.0		
	.190	32.2		8.2
	.200	19.5	22.0	
	.250		21.8	
	.300	off scale at 4.3x10^{-3}		
	.320		22.3	
	.380		21.5	
	.450		21.5	8.0
	.490			7.8
	.500			
	.525		22.2	
	.550			
	.575	.24		
	.600	.42		
	.700	.22		7.1
	.800	.62		
	.900	off scale at 4.3x10^{-3}		
	.925		21.0	
	.950	3.39		
	1.0	1.31	20.6	
	1.05		20.9	
	1.08	2.93		
	1.1	.69	20.5	
	1.15	.19		
	1.2			7.1
	1.25	.24	20.3	
	1.3		20.1	
	1.33	1.07		
	1.35	1.36	19.8	
	1.4	off scale at 4.3x10^{-3}		
	1.45	.42	19.3	
	1.49	.17		
	1.5	.22		
6	1.57	.09	19.3	6.6

OUTBOUND SLANT CLIMB

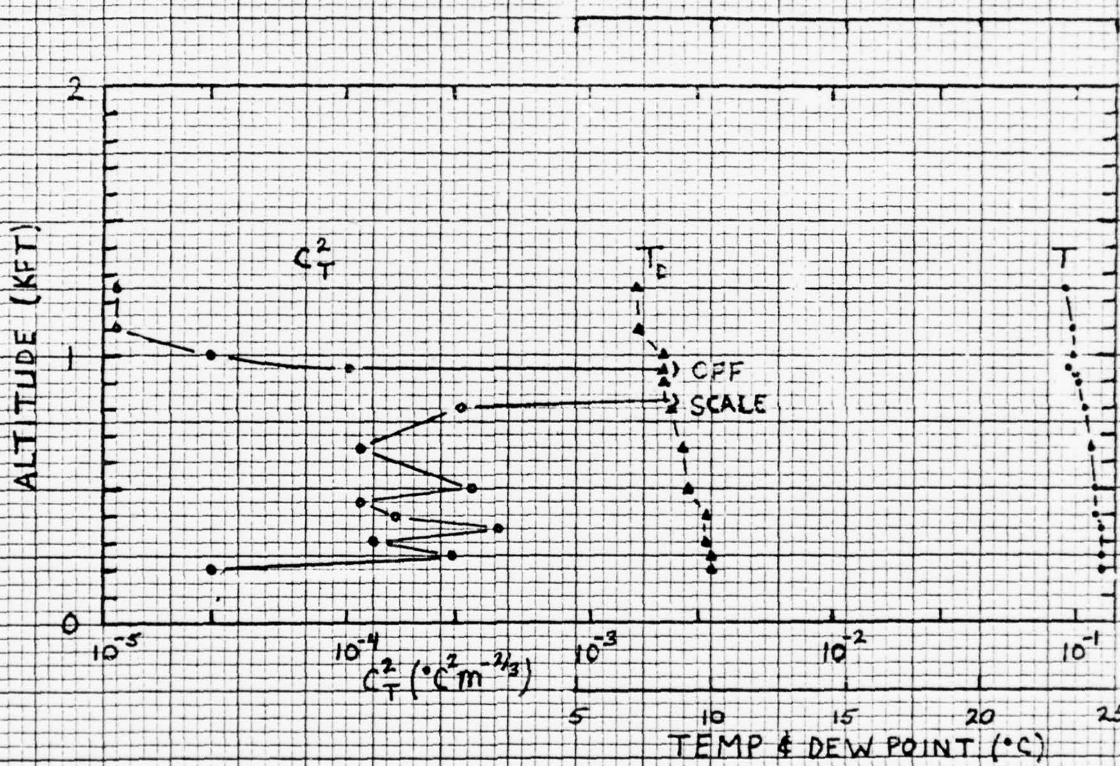


DAHLGREN, VA NSWC TEST RANGE
19 APRIL 1977 1615 EST OUTBOUND SLANT
CLIMB FROM TARGET SITE TO 6 NAUTICAL
MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
19 April 1977 1615 EST Outbound Slant Climb
From Target Site To 6 NM Down Range

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} ($°C^2m^{-2/3}$)		T(C)	T_D(C)
0	.120	13.4		22.8	15.2
	.150	10.0	cross shore	23.9	12.5
	.200	.37		24.9	11.1
	.300	.03		24.9	10.9
	.400	.05			
	.500	.36		24.5	9.8
	.550	.91			
	.600	1.38		24.3	9.8
	.650	.087		24.3	9.4
	.700	1.0			
	.750	1.49		24.2	9.0
	.775	.56		24.2	8.7
	.800	1.44		24.1	8.7
	.850	2.41		24.3	7.9
	.900	.087		24.2	7.8
	1.0	.015		24.0	7.9
	1.1	2.61			
	1.15	.032			
	1.2	.25		23.5	7.5
	1.25	.82		23.4	7.7
	1.3	.15		23.2	7.7
	1.4	.05		22.9	7.2
	1.45	.25		22.7	7.2
	1.5	.25		22.6	7.1
6	1.6	.015		22.4	7.1

DOWN SPIRAL SOUNDING

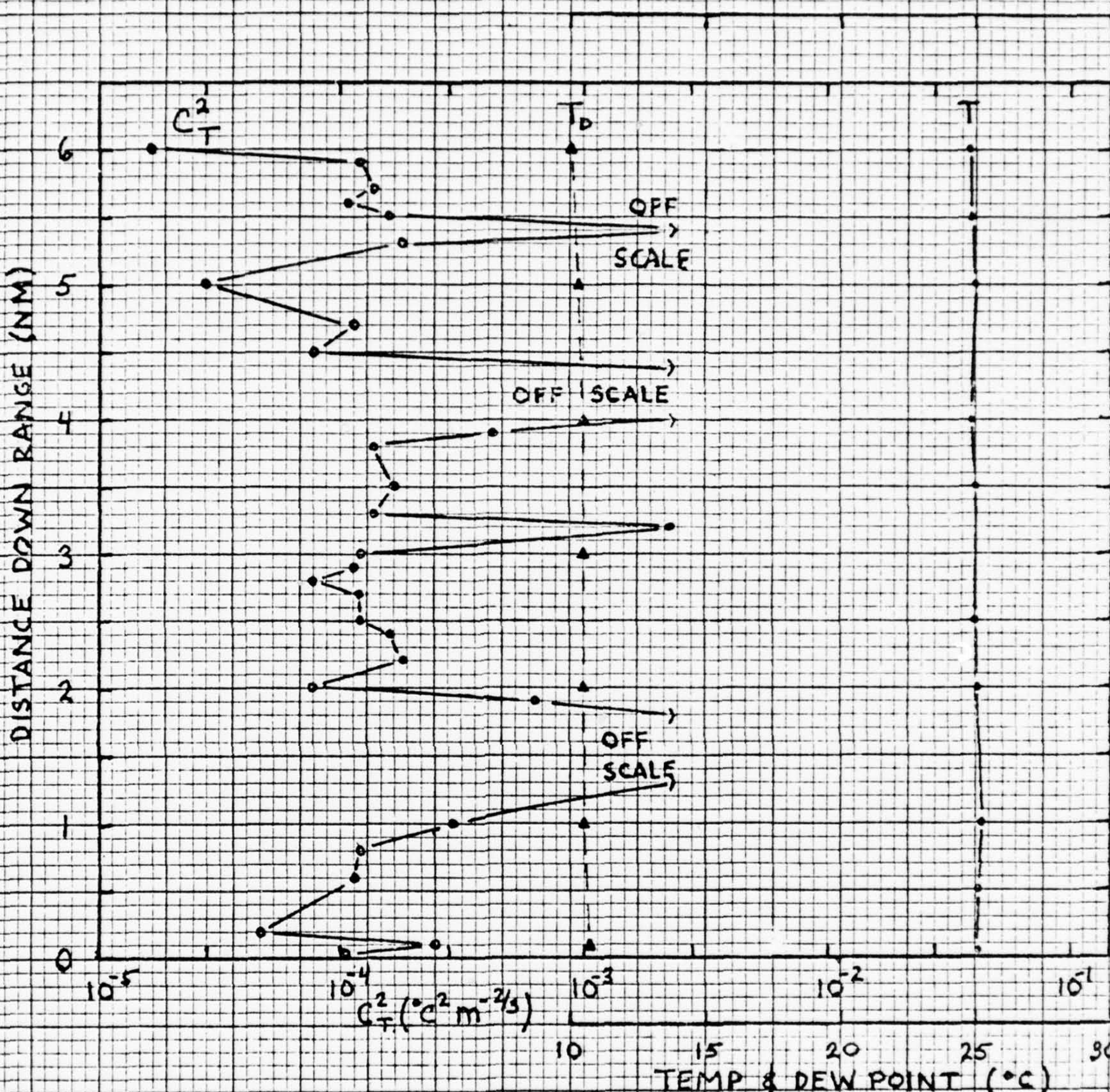


DAHLGREN, VA NSWC TEST RANGE
19 APRIL 1977 1620 EST DOWN SPIRAL SOUNDING
7 NAUTICAL MILES DOWN RANGE FROM TARGET SITE

Dahlgren, VA NSWC Test Range
19 April 1977 1620 EST Down Spiral Sounding
7 NM Down Range From Target Site

Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
1.25	.015	23.1	7.2
1.1	.015	23.4	7.3
1.0	.05	23.4	8.2
.950	.11	23.3	8.2
.940			
.900	off scale at 4.4	23.6	8.2
.825			
.800	.52	23.8	8.5
.650	.15	24.1	8.9
.500	.56	24.3	9.1
.450	.15		
.400	.28	24.3	9.8
.350	.66	24.5	9.8
.300	.2	24.5	9.8
.250	.49	24.5	10.0
.200	.05	24.5	10.0

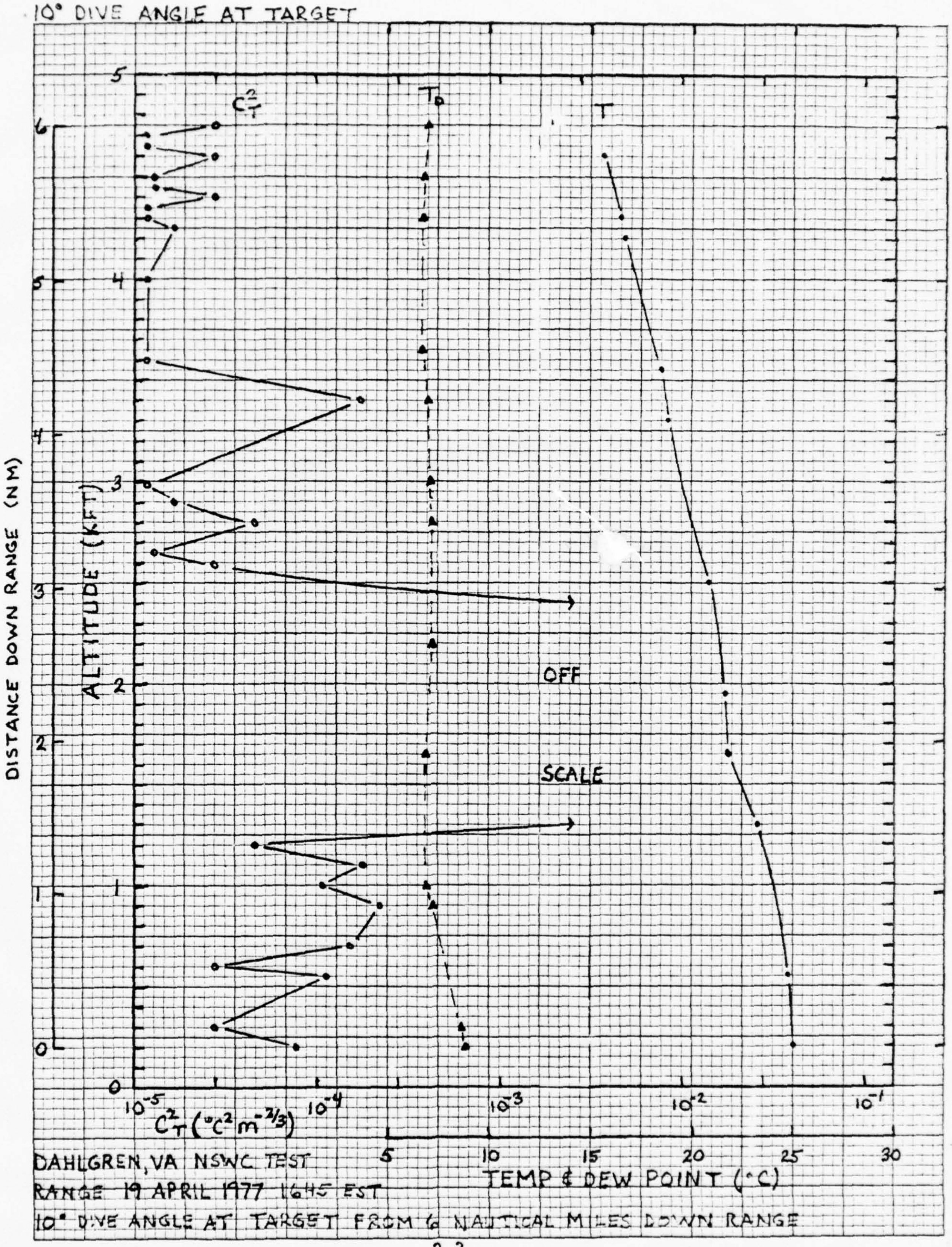
200 FT LEVEL RUN



DAHLGREN, VA NSWC TEST RANGE
19 APRIL 1977 1630 EST 200 FT LEVEL RUN
FROM 6 NAUTICAL MILES DOWN RANGE
BACK TO TARGET SITE

Dahlgren,VA NSWC Test Range
19 April 1977 1630 EST 200 Foot Level Run
From 6 NM Down Range Back To The Target Site

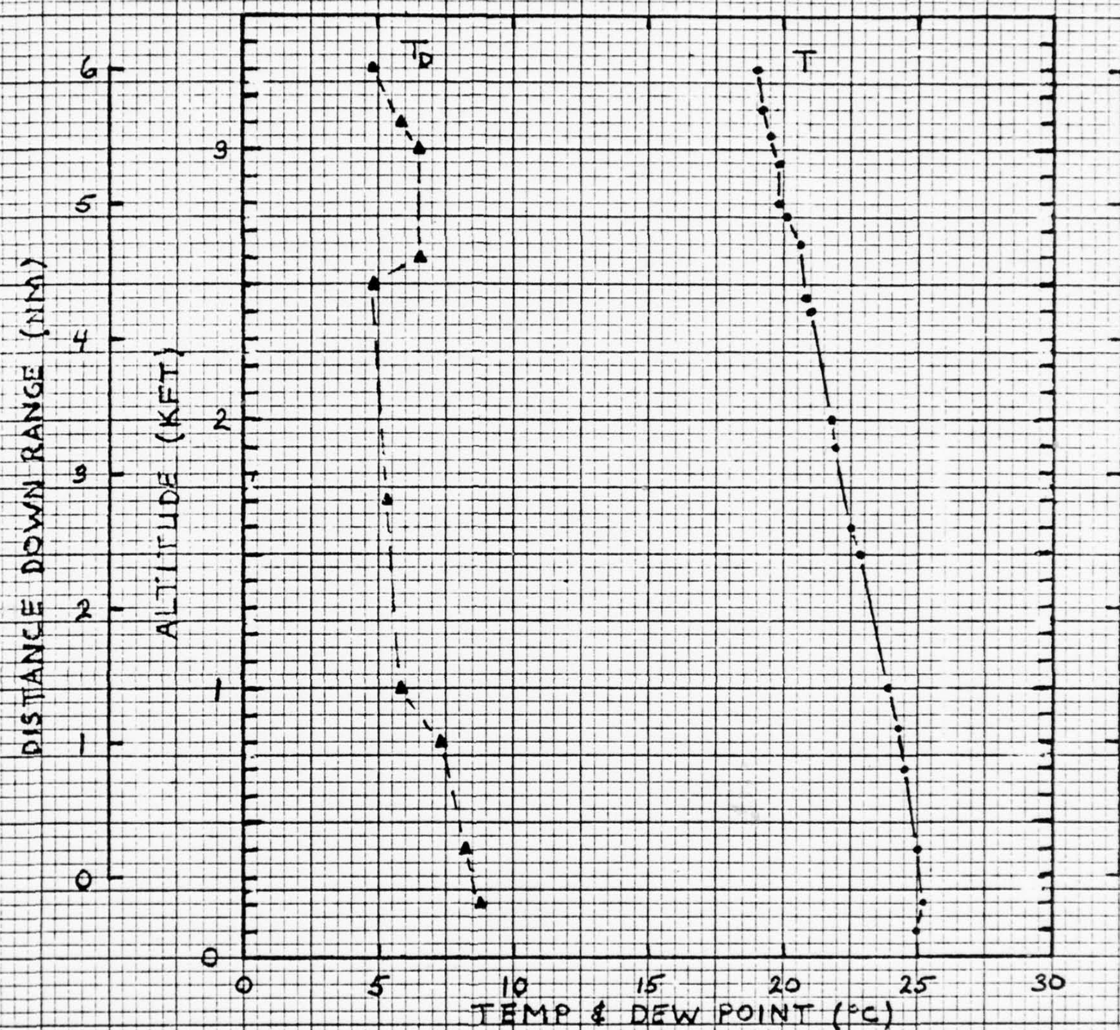
Distance Down Range (NM)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0.0	.11	25.1	10.7
0.1	.45		
0.2	.07		
0.5		25.1	
0.6	.15		
0.8	.17		
1.0	.52	25.2	10.5
1.3	off scale		
1.8	at 4.4x10^{-3}		
1.9	.82		
2.0	.09	25.1	10.5
2.2	.33		
2.4	.28		
2.5	.17	25.0	
2.7	.17		
2.8	.09		
2.9	.15		
3.0	.17	25.0	10.5
3.2	4.2		
3.3	.22		
3.5	.30	25.0	
3.8	.22		
3.9	.66		
4.0	off scale	24.9	10.5
4.4	at 4.4x10^{-3}		
4.5	.09	24.9	
4.7	.15		
5.0	.05	25.0	10.3
5.3	.33		
5.4	off scale at 4.4x10^{-3}		
5.5	.28	24.9	
5.6	.13		
5.7	.22		
5.9	.17		
6.0	.03	24.8	10.0


10° DIVE ANGLE AT TARGET
C_T^2
T_D
T
OFF
SCALE
DISTANCE DOWN RANGE (NM)
ALTITUDE (KFT)
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
C_T^2 ($°C^2 m^{-2/3}$)
5
10
15
20
25
30
TEMP & DEW POINT (°C)
DAHLGREN, VA NSWC TEST
RANGE 19 APRIL 1977 1645 EST
10° DIVE ANGLE AT TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
19 April 1977 1645 EST 10° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	$C_T^2 \times 10^{-3}$ ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0	.200	.09	25.0	8.7
	.300	.05		8.6
	.550	.15	24.8	
	.600	.05		
	.700	.26		
	.900	.41		7.2
	1.0	.13		6.9
	1.1	.32		
	1.2	.07		
	1.3		22.3	
	1.65		21.8	6.9
	1.95	off scale	21.6	
	2.2	at 4.6×10^{-3}		7.2
	2.4			
	2.5		20.9	
	2.59	.05		
	2.65	.02		
	2.8	.07	13.2	7.2
	2.9	.03		
	2.98	.016		
	3.0		13.1	7.1
	3.1	.016		
	3.3		18.9	
	3.4	.32		7.0
	3.55		18.5	
	3.6	.016		
	3.65			6.7
	4.0	.016		
	4.2	[illegible]	16.6	
	4.25	.03		
	4.3	.016	16.5	6.7
	4.35	.016		
	4.4	.05		
	4.45	.02		
	4.5	.02		6.8
	4.6	.05	15.7	
	4.65	.016		
	4.7	.016		
6	4.75	.05		7.0

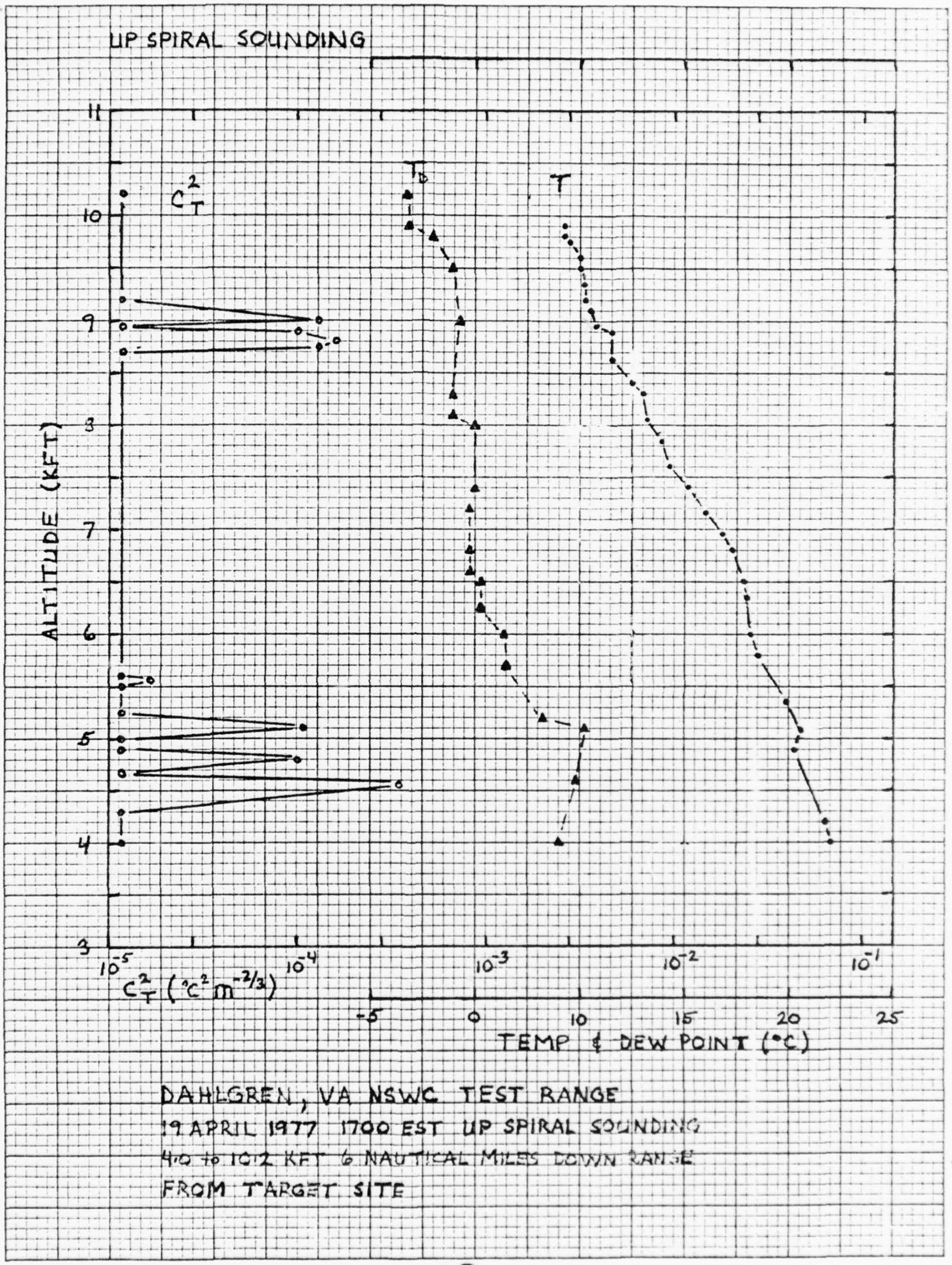
OUTBOUND SLANT CLIMB



DAHLGREN, VA NSWC TEST RANGE
19 APRIL 1977 1655 EST OUTBOUND SLANT
CLIMB FROM TARGET SITE TO 6 NAUTICAL
MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
19 April 1977 1655 EST Outbound Slant Climb
From Target Site To 6 NM Down Range

Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.100	25.0	
	.200	25.2	8.7
	.400	25.0	8.2
	.700	24.5	
	.800		7.3
	.850	24.3	
	1.0	23.9	5.8
	1.5	22.8	
	1.6	22.5	
	1.7		5.3
	1.9	21.9	
	2.0	21.8	
	2.4	21.0	
	2.45	20.8	
	2.5		4.8
	2.6		6.5
	2.65	20.6	
	2.75	20.1	
	2.8	19.9	
	2.95	19.9	
	3.0		6.5
	3.05	19.5	
	3.1		5.8
	3.15	19.2	
6	3.3	19.0	4.8



K&E 5 X 5 TO THE CENTIMETER 46 1612
18 X 24 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

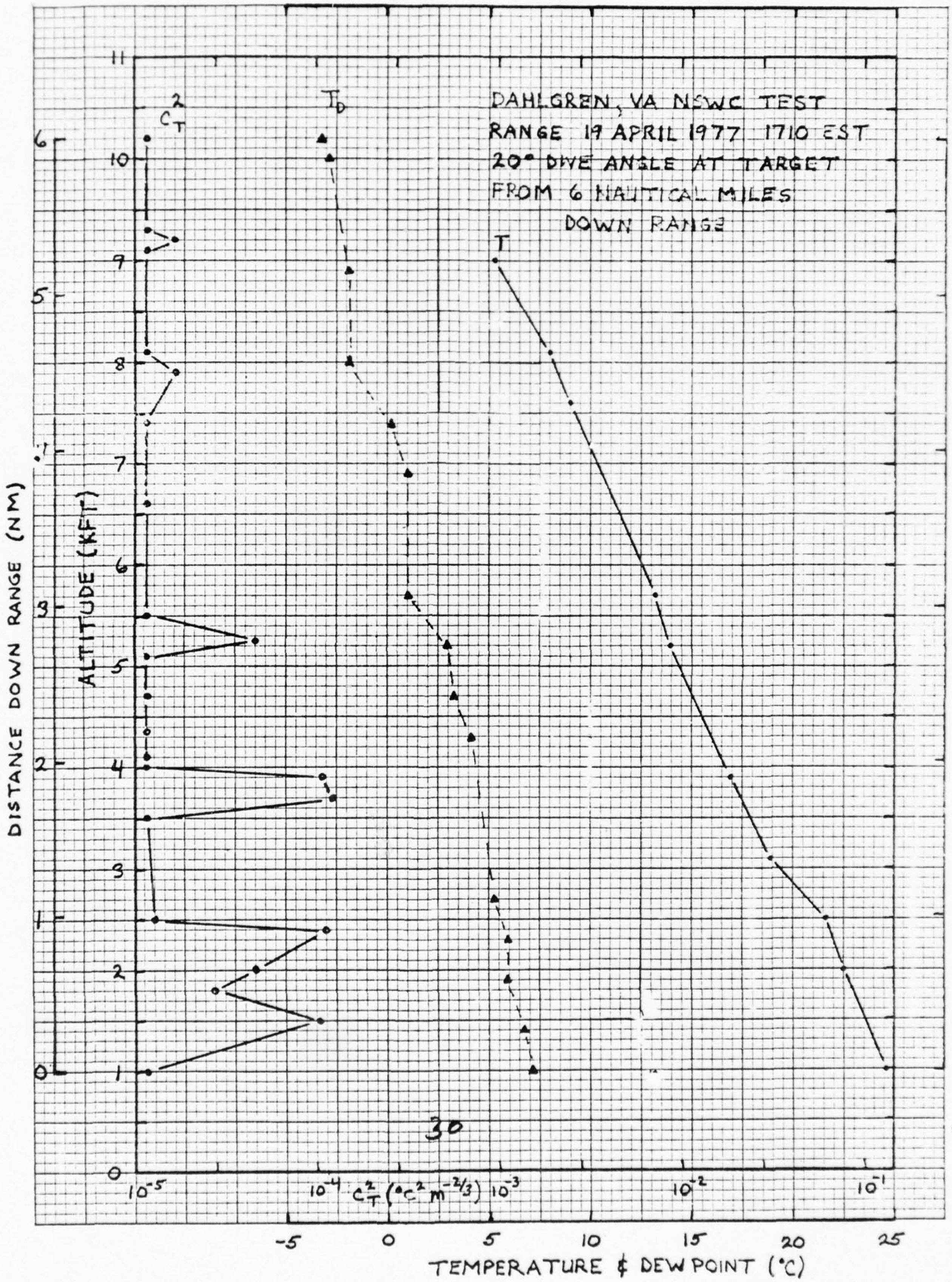
Dahlgren, VA NSWC Test Range
19 April 1977 1700 EST Up Spiral Sounding
4.0 to 10.2 kft 6 NM Down Range From The Target Site

Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
4.0	.016	17.0	4.0
4.2		16.7	
4.3	.016		
4.55	.58		
4.6			4.8
4.65	.016		
4.7	.016		
4.8	.10		
4.9	.016	15.3	
5.0	.016		
5.1	.13	15.5	5.2
5.2			3.2
5.25	.016		
5.35		14.9	
5.5	.016		
5.55	.03		
5.6	.016		
5.7			1.5
5.8		13.5	
6.0		13.2	1.4
6.25			0.3
6.35		13.0	
6.5		12.8	0.3
6.6			-0.3
6.8		12.3	-0.3
6.95		11.7	
7.15		11.0	
7.2			-0.3
7.4		10.1	0.0
7.6		9.3	
7.85		8.9	
7.95		8.9	
8.0			0.0
8.05		8.2	-1.1
8.3		8.0	-1.1
8.4		7.5	
8.5			
8.62		6.5	
8.7	.016		
8.75	.2		
8.8	.28		
8.9	.10	6.5	
8.95	.016	5.7	
9.0	.2		-0.8
9.1	.016	5.5	

Dahlgren, VA NSWC Test Range
19 April 1977 1700 EST Up Spiral Sounding

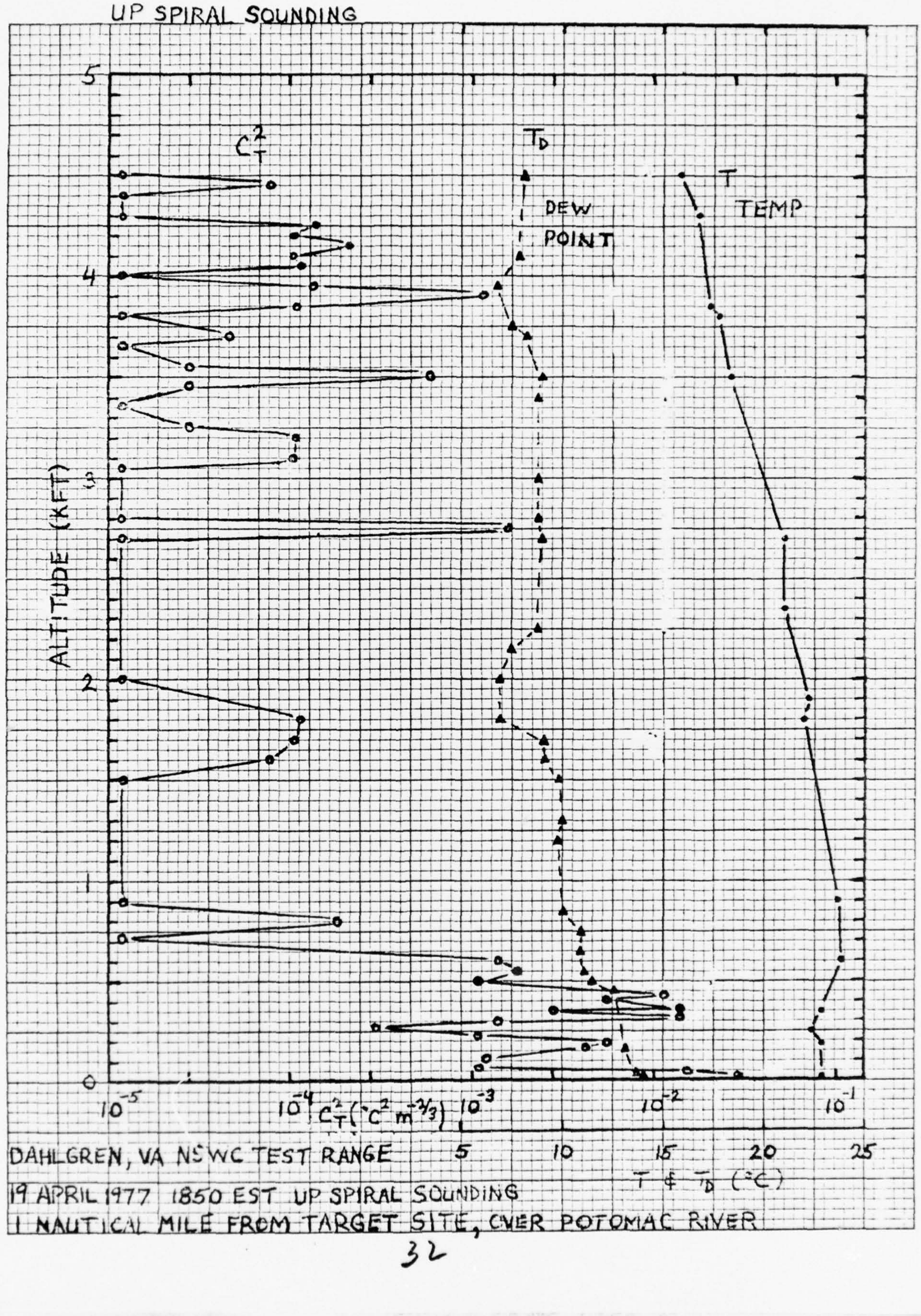
Altitude (kft)	C_T^2 x10^{-3} ($^\circ C^2 m^{-2/3}$)	T(C)	T_D(C)
9.2		5.3	
9.35		5.2	
9.5		5.0	-1.1
9.6		5.0	
9.75		4.5	
9.8		4.3	-2.0
9.9		4.3	-3.2
10.2	.016		-3.3

20° DIVE ANGLE AT TARGET



Dahlgren, VA NSWC Test Range
19 April 1977 1710 EST 20° Dive Angle At Target
From 6 NM Down Range

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} (°$C^2m^{-2/3}$)	T(C)	T_D(C)
0	1.0	.016	24.6	7.1
	1.4			6.7
	1.5	.11		
	1.8	.05		
	1.9			5.9
	2.0	.07	22.5	
	2.3			5.9
	2.4	.15		
	2.5	.02	21.6	
	2.7			5.3
	3.1		18.9	
	3.5	.016		
	3.7	.18		
	3.9	.13	16.9	
	4.0	.016		
	4.1	.016		
	4.3			4.1
	4.35	.16		
	4.7	.016		3.3
	5.1	.016		
	5.2		13.9	2.9
	5.25	.07		
	5.5	.016		
	5.7		13.2	1.0
	6.6	.016		
	6.9			1.0
	7.4	.016		0.2
	7.6		9.0	
	7.9	.03		
	8.0			-1.9
	8.1	.016	8.0	
	8.9			-1.9
	9.0		5.3	
	9.1	.016		
	9.2	.03		
	9.3	.016		
	10.0			-2.9
6	10.2	.016		-3.3



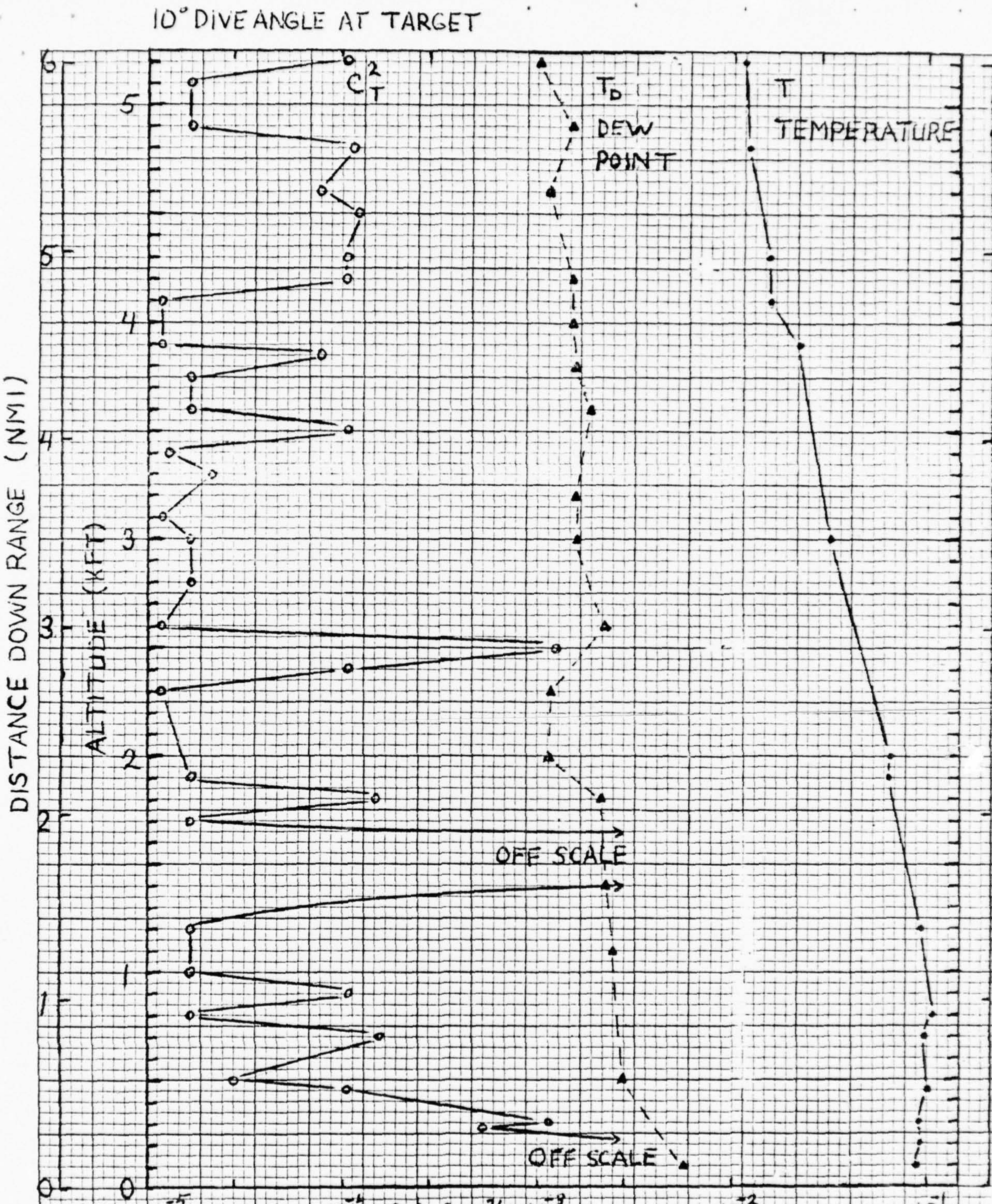
UP SPIRAL SOUNDING
ALTITUDE (KFT)
C_T^2
T_D
DEW POINT
T
TEMP
10^-5
10^-4
C_T^2 (°C^2 m^-2/3)
10^-3
10^-2
10^-1
DAHLGREN, VA NSWC TEST RANGE
5
10
15
20
25
T & T_D (°C)
19 APRIL 1977 1850 EST UP SPIRAL SOUNDING
1 NAUTICAL MILE FROM TARGET SITE, OVER POTOMAC RIVER

Dahlgren, VA NSWC Test Range
19 April 1977 1850 EST Up Spiral Sounding
1 NM Down Range From Target Site

Altitude (kft)	C_T^2 x10^{-3} ($^\circ C^2 m^{-2/3}$)	T(C)	T_D(C)
.010	52	22.9	14.0
.025	36.7		13.7
.035	21.9		
.040	27.7		
.060	1.2		
.080	2.9		
.100	1.7		
.160	5.6		13.1
.180	1.2	22.9	
.190	6.6		
.230	1.2		
.250		22.4	
.270	.51		
.300	2.41		
.320	12.4		
.330	4.0		
.350	11.4	22.8	
.390	6.6		
.420	9.5		
.450	1.22		13.0
.480	3.1		
.500	1.2		11.5
.550	3.1		11.1
.600	2.4		
.650		23.9	10.9
.710	.016		
.750			10.9
.800	.33		
.850			10.0
.900	.016	23.7	
1.2			9.8
1.3			10.0
1.5	.016		9.8
1.6	.09		9.1
1.7	.11		9.1
1.8	.15	22.2	
2.0	.016		6.9
2.15			7.5
2.25			8.8
2.35		21.0	
2.6		21.0	
2.7	.016		9.0
2.75	2.74		
2.8	.016		8.8
3.0			8.8
3.05	.016		
3.1	.11		

Dahlgren, VA NSWC Test Range
19 April 1977 1850 EST Up Spiral Sounding

Altitude (kft)	C_T^2 x10^{-3} ($^\circ C^2 m^{-2/3}$)	T(C)	T_D(C)
3.2	.13		
3.25	.05		
3.35	.016		
3.4	.05		8.8
3.5	.79	18.3	9.0
3.55	.05		
3.65	.016		
3.7	.07		8.2
3.75			7.5
3.8	.016	17.7	
3.85	.13	17.3	7.5
3.9	1.5		
3.95	.21		6.8
4.0	.016		
4.05	.15		
4.1	.11		7.9
4.15	.39		
4.2	.11		
4.25	.22		
4.3	.016	16.7	
4.4	.016		
4.45	.09		
4.5	.016	15.8	8.1

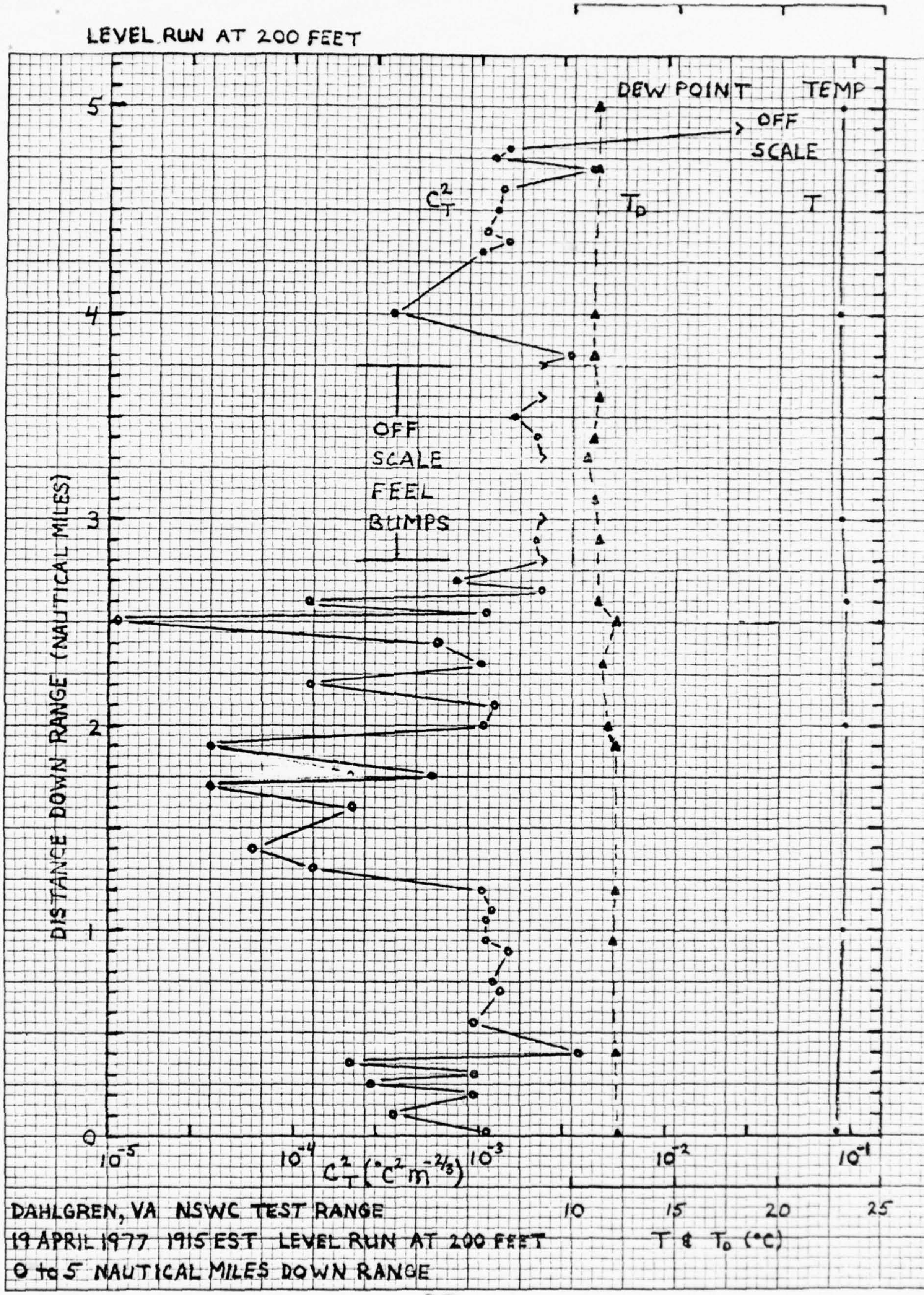


DAHLGREN, VA NSWC TEST RANGE

19 APRIL 1977 1900 EST 10° DIVE ANGLE AT TARGET FROM 6 NAUTICAL MILES DOWN RANGE (OVER POTOMAC RIVER)

Dahlgren, VA NSWC Test Range
19 April 1977 1900 EST 10° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0	.100		23.0	12.3
	.200	off scale at 4.6	23.2	
	.275			
	.280	.75		
	.300	1.5	23.2	
	.450	.11	23.5	
	.500	.05		9.4
	.700	.27	23.4	
	.800	.03	23.8	
	.900	.13		
	1.0	.03		
	1.1			9.0
	1.2	.03	23.1	
	1.4	off scale		8.6
	1.65	at 4.6		
	1.7	.03		
	1.8	.25		8.4
	1.9	.03	21.7	
	2.0		21.8	6.0
	2.3	.016		6.1
	2.4	.13		
	2.5	1.87		
	2.6	.016		8.6
	2.8	.03		
	3.0	.03	19.0	7.3
	3.1	.016		
	3.2			7.3
	3.3	.04		
	3.4	.02		
	3.5	.13		
	3.6	.03		7.9
	3.75	.03		
	3.8			7.3
	3.85	.09		
	3.9	.016	17.5	
	4.0			7.1
	4.1	.016	16.3	
	4.2	.11		7.1
	4.3	.11	16.2	
	4.5	.17		
	4.6	.09		6.0
	4.8	.15	15.2	
	4.9			7.1
	5.1	.03		
6	5.2	.11	15.0	5.6



LEVEL RUN AT 200 FEET
DEW POINT
TEMP
OFF SCALE
C_T^2
T_D
T
OFF SCALE FEEL BUMPS
DISTANCE DOWN RANGE (NAUTICAL MILES)
0
1
2
3
4
5
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
C_T^2 ($°C^2 m^{-2/3}$)
10
15
20
25
T & T_D (°C)
DAHLGREN, VA NSWC TEST RANGE
19 APRIL 1977 1915 EST LEVEL RUN AT 200 FEET
0 to 5 NAUTICAL MILES DOWN RANGE

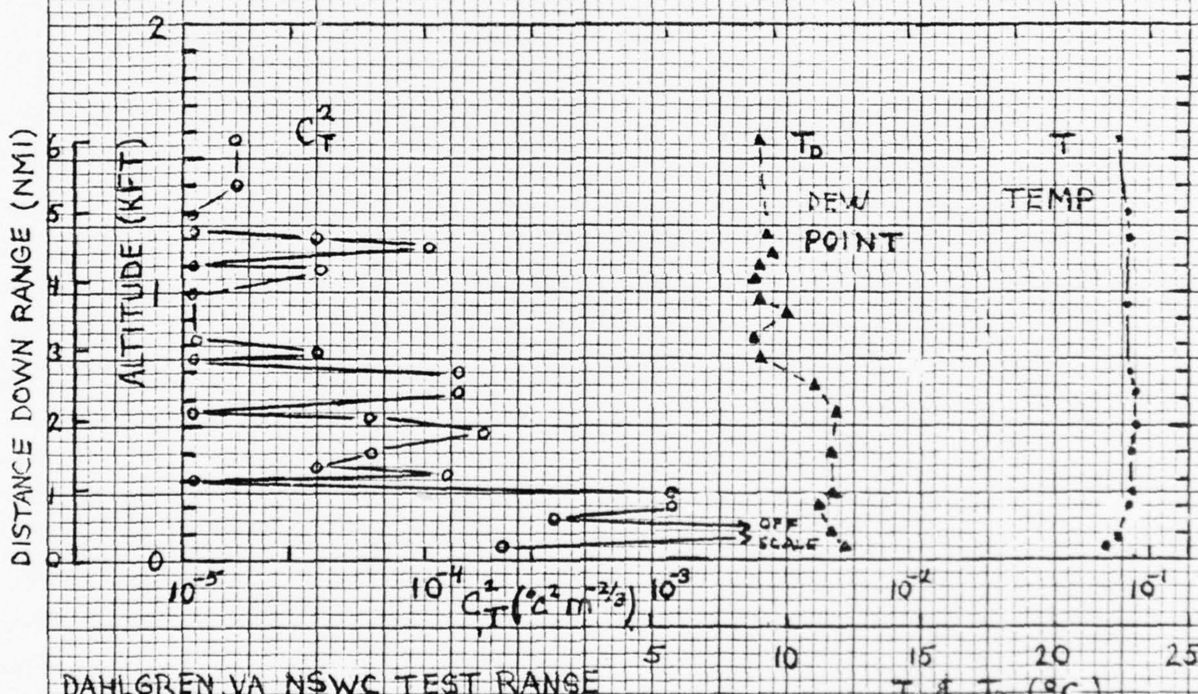
Dahlgren, VA NSWC Test Range
19 April 1977 1915 EST 200 Foot Level Run
From Target Site To 5 NM Down Range

Distance Down Range (NM)	C_T^2 $\times 10^{-3}$ ($°C^2 m^{-2/3}$)		T(C)	T_D(C)
0	1.28		22.8	12.3
0.1	.58			
0.2	.97			
0.25	.47			
0.3	.97			
0.35	.37			
0.4	5.8			12.1
0.55	.97			
0.7	2.02			
0.75	1.63			
0.9	2.44			
0.95	1.28			12.0
1.0			23.1	
1.05	1.28			
1.1	2.02			
1.2	1.12			12.1
1.3	.2			
1.4	.08			
1.65	.39			
1.7	.06			
1.75	.77			
1.9	.06			12.1
2.0	1.2		23.2	11.7
2.1	1.61			
2.2	.18			
2.3	1.02			11.5
2.4	.08			
2.5	.014			12.1
2.55	1.3			
2.6	.18		23.2	11.2
2.65	4.06			
2.7	.9			
2.8	off scale at 4.2			
2.9	3.9			11.2
3.0			23.0	
3.1	off scale at 4.2	feel		11.0
3.3		bumps		10.6
3.4	3.81			11.0
3.5	2.67			
3.6	off scale			11.2
3.75	at 4.2			
3.8	5.46			11.0
4.0	.58		22.9	11.0
4.3	1.12			
4.35	2.44			
4.4	1.45			
4.45	1.63			
4.5	1.82			
4.6	2.22			
4.7	6.49			11.1

Dahlgren, VA NSWC Test Range
19 April 1977 1915 EST 200 Level Run

Distance Down Range (NM)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
4.75	1.63		
4.8	2.44		
4.9	off scale at 4.8x10^{-2}		
5.0		23.0	11.1

3° DIVE ANGLE AT TARGET



DAHLGREN, VA NSWC TEST RANGE

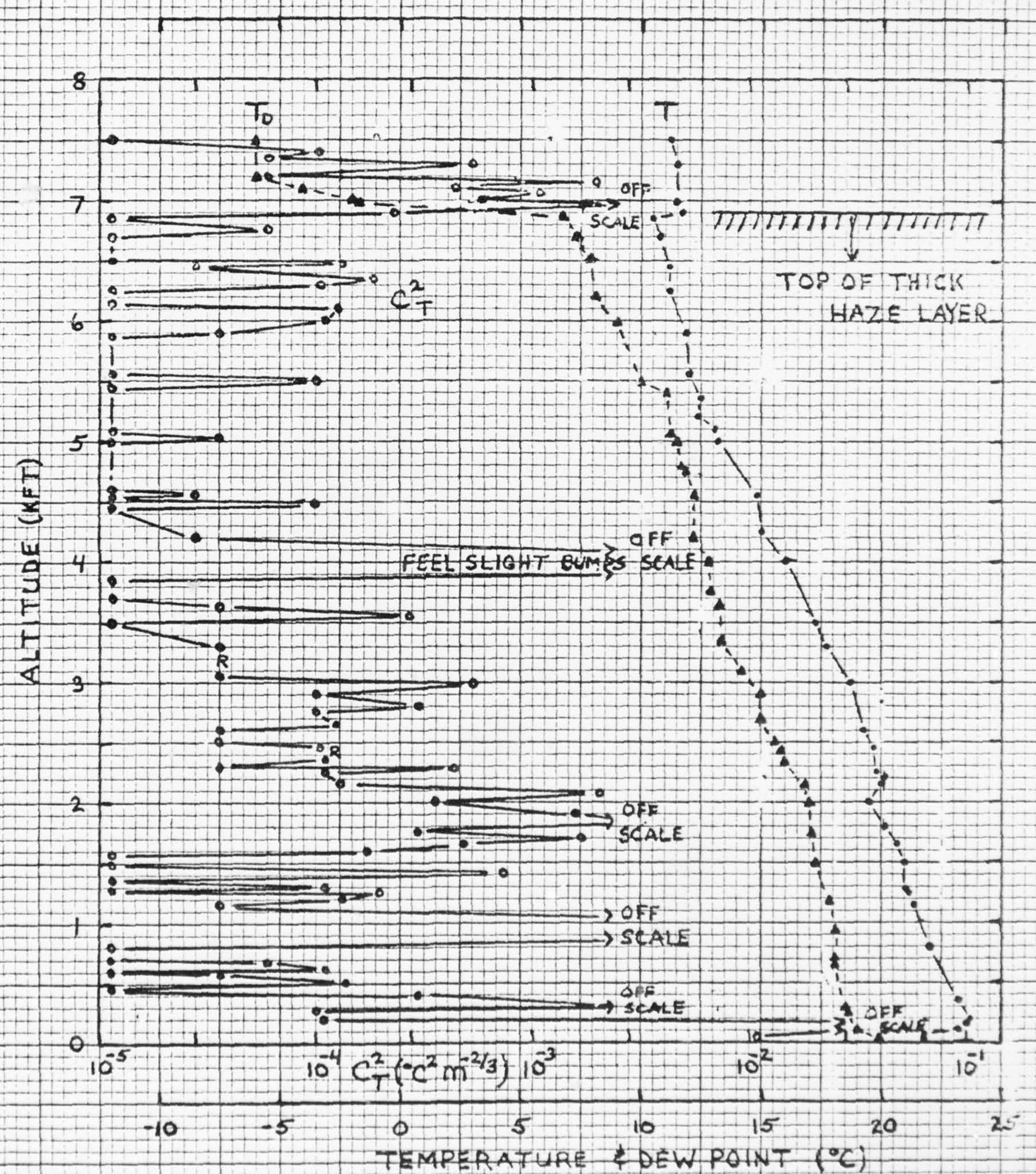
19 APRIL 1977 1920 EST 3° DIVE ANGLE AT

TARGET FROM 6 NAUTICAL MILES DOWN RANGE (OVER POTOMAC RIVER)

Dahlgren, VA NSWC Test Range
19 April 1977 1920 EST 3° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} (°$C^2m^{-2/3}$)	T(C)	T_D(C)
0	.050	.39	21.9	12.1
	.075		22.3	
	.100	off scale at 4.2		11.6
	.150	.58		
	.200	1.15	22.6	11.2
	.250	1.15	22.9	11.6
	.300	.014		
	.325	.18		
	.350	.06		
	.400	.08	22.9	11.6
	.450	.31		
	.475	.37		
	.500		23.0	
	.525	.08		
	.550	.014		11.8
	.625	.21	23.0	
	.650	.10		11.0
	.700	.23	22.8	
	.710	.03		
	.750	.014		9.0
	.775	.06		
	.800	.014		
	.825			8.8
	.900	.014		
	.925			10.0
	.950		22.7	
	.975			9.0
	1.0	.014		
	1.05			8.8
	1.09	.62		
	1.1	.014		9.0
	1.13	.03		
	1.15			9.5
	1.16	.12		
	1.18	.03		
	1.2	.06	22.8	
	1.22	.014		9.2
	1.3	.014	22.8	
	1.4	.03		
6	1.57	.03	22.4	9.0

DAHLGREN, VA NSWC TEST RANGE
21 APRIL 1977 1855 EST UP SPIRAL SOUNDING
6 NAUTICAL MILES DOWN RANGE FROM TARGET SITE



R= DATA COLLECTION INTERRUPTED BY RADIO COMMUNICATION

Dahlgren, VA NSWC Test Range
21 April 1977 1855 EST Up Spiral Sounding
6 NM Down Range From Target Site

Altitude (kft)	C_T^2 $x10^{-3}$ ($^\circ C^2 m^{-2/3}$)	T(C)	T_D(C)
.010	10.3	21.7	19.9
.040		21.7	19.9
.090	11.7		
.100	off scale	23.2	19.0
.150	at $49.2x10^{-3}$	23.5	
.200	.13	23.6	
.250			18.6
.275	.10		
.300	off scale at 4.3		18.5
.350		23.2	
.400	.53		
.475	.015		
.525	.23		
.575	.06		
.600	.015		
.625	.14		
.650			18.1
.675	.08		
.700	.015		18.1
.800	.015	22.0	
.850			
.950	off scale at 4.3		18.1
1.05			
1.15	.06	21.4	
1.18			17.8
1.2	.21		
1.25	.37	21.2	
1.28	.015	21.0	
1.3	.14		
1.35	.015		
1.4	.87		
1.45	.21		
1.49	.015		
1.5		21.0	17.3
1.56	.015		
1.6	.31		
1.65	.71	20.7	
1.7	3.02		
1.75	1.23		17.1
1.8	off scale	20.2	
1.85	at 4.3		
1.9	2.73		
2.0	.6	19.5	17.0
2.08	3.75		
2.15	.2	20.0	16.8
2.2	.2	20.1	
2.25	.14	19.8	

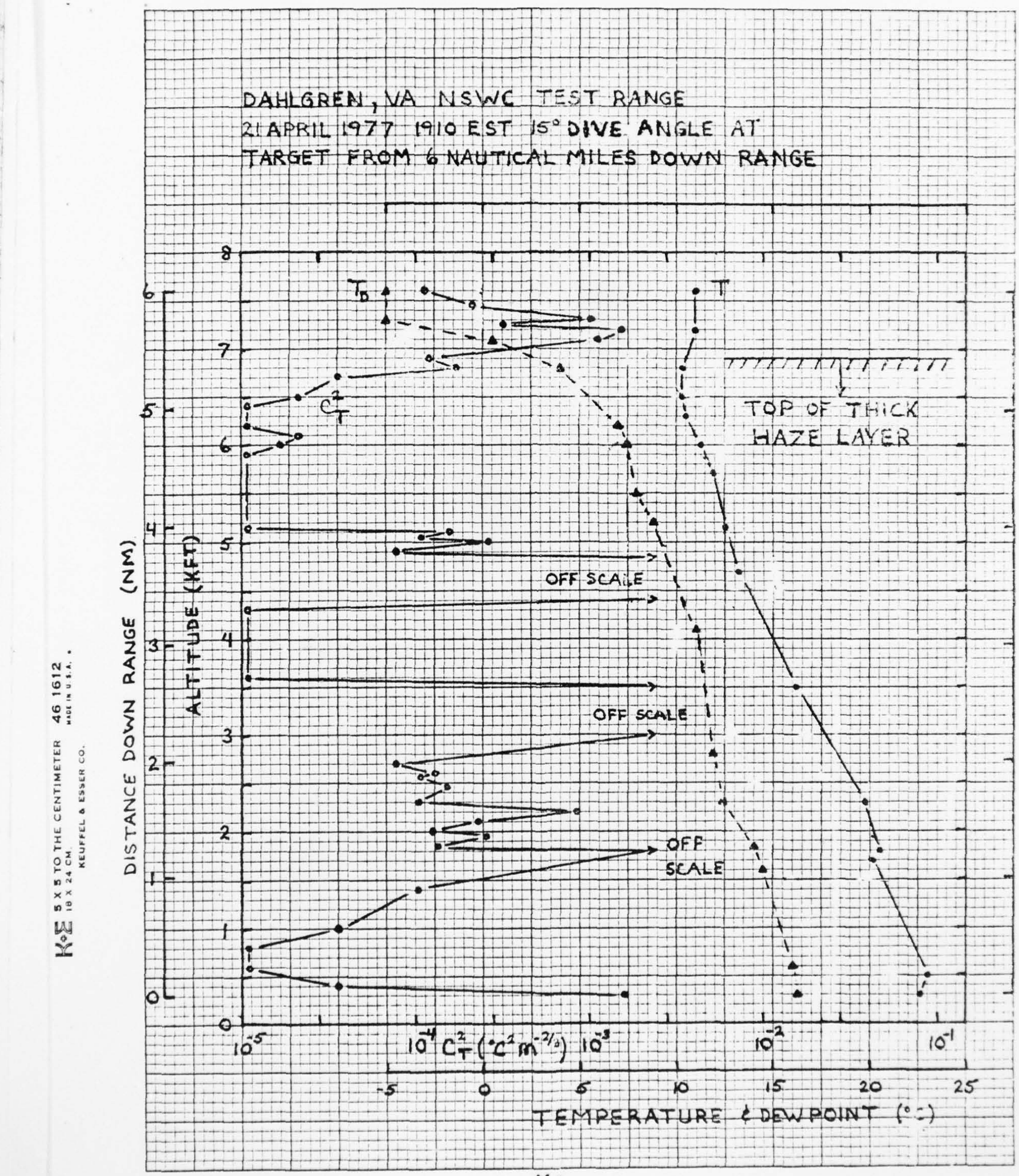
Dahlgren, VA NSWC Test Range
21 April 1977 1855 EST Up Spiral Sounding

Altitude (kft)	$C_T^2 \times 10^{-3}$ ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
2.28	.67		
2.3	.06		
2.35	.14		16.0
2.4	Radio		15.8
2.45	.12	19.7	15.8
2.5	.06		15.6
2.6	.06	19.3	
2.65	.19		
2.7			15.0
2.75	.10		
2.8	.53		
2.9	.10		15.0
2.98	.75		
3.0		18.7	
3.05	.06		
3.1	Radio		14.2
3.3	.06	17.7	
3.35			13.3
3.5	.015		
3.55	.49		
3.6	.06		
3.65	.06		13.3
3.7	.015		
3.75			12.9
3.85	.015		
3.9	off scale		
4.0	at 4.3	16.0	12.8
4.1	feel slight bumps		
4.2	.05		12.2
4.25		15.0	
4.45	.015		
4.48	.1		
4.5	.015		
4.55	.05	14.8	12.2
4.6	.015		
4.75			11.9
4.8			11.7
5.0	.015	13.2	11.5
5.02	.06		
5.05	.015		11.3
5.1		13.1	
5.2		12.4	
5.35		12.5	
5.4			11.1
5.45	.015		
5.5	.10		10.0
5.55	.015	12.0	

Radio = Data Collection Interrupted By Radio Communication

21 April 1977 1855 EST Up Spiral Sounding

Altitude (kft)	$C_T^2 \times 10^{-3}$ ($°C^2 m^{-2/3}$)	T(C)		T_D(C)
5.88	.015			
5.9	.06	11.9		
6.0	.14			9.0
6.1	.19			
6.15	.015			
6.2				8.1
6.25	.015	11.2		
6.3	.12			
6.35	.34			
6.45	.05	11.2		
6.47	.21			
6.5	.015			7.9
6.7	.015	10.8		7.3
6.73	.08			
6.78	.08			
6.85	.015	10.5		
6.88				6.7
6.9	.43	11.7	Haze Top	
6.93	1.59			
6.95	off scale at 4.3			
6.98				-1.7
7.0	.79	11.5		-2.0
7.05	1.28			
7.1	.67			-4.1
7.13	3.64			
7.2	.08			-6.0
7.23	.46			
7.3	.75	11.5		
7.35	.08			
7.4	.12			
7.5	.015	11.2		-6.0

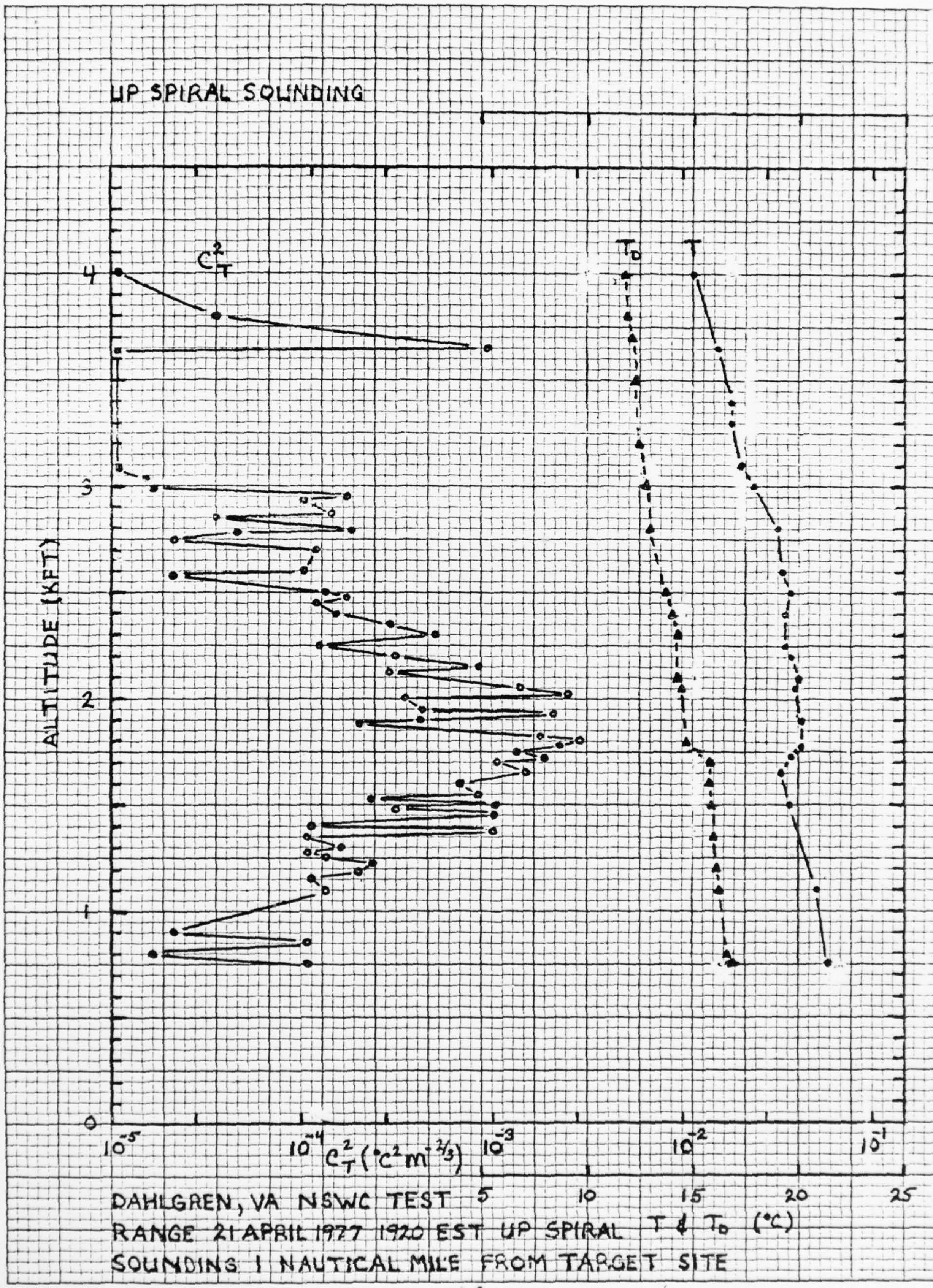

DAHLGREN, VA NSWC TEST RANGE
21 APRIL 1977 1910 EST 15° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE
T_D
T
C_T^2
TOP OF THICK
HAZE LAYER
OFF SCALE
OFF SCALE
OFF
SCALE
ALTITUDE (KFT)
DISTANCE DOWN RANGE (NM)
10^{-5}
10^{-4} C_T^2 ($°C^2 m^{-2/3}$) 10^{-3}
10^{-2}
10^{-1}
-5
0
5
10
15
20
25
TEMPERATURE & DEWPOINT (°C)
K+E 5 X 5 TO THE CENTIMETER 46 1612
18 X 24 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

Dahlgren, VA NSWC Test Range
21 April 1977 1910 EST 15° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	$C_T^2 \times 10^{-3}$ ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0	.300	2.89	22.6	16.3
	.400	.06		
	.500		23.0	
	.600	.013		16.0
	.800	.013		
	1.0	.06		
	1.4	.11		
	1.6			14.5
	1.7		20.2	
	1.8	off scale at 4.4	20.5	
	1.85	.21		14.0
	1.95	.46		
	2.0	.19		
	2.1	.43		
	2.2	.94		
	2.3	.11	19.8	12.4
	2.45	.26		
	2.55	.13		
	2.6	.20		
	2.7	.09		
	2.8			11.9
	3.0	off scale		
	3.5	at 4.4	16.2	
	3.6	.013		
	4.1			11.0
	4.3	.013		
	4.4			
	4.7	off scale at 4.4	13.2	
	4.85			
	4.9	.09		
	5.0	.49		
	5.05	.13		
	5.1	.27		
	5.15	.013	12.5	
	5.2			8.8
	5.5			7.9
	5.7		11.9	
	5.9	.013		
	6.0	.03	11.3	7.5
	6.05	.013		
	6.1	.04		
	6.2	.013		6.7
	6.3		10.5	
	6.4	.013		
	6.5	.04	10.3	
	6.7	.06		
	6.8	.31	10.3	4.0

Dahlgren, VA NSWC Test Range
21 April 1977 1910 EST 15°Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} ($^\circ C^2 m^{-2/3}$)	T(C)	T_D(C)
	6.9	.18		
	7.1	1.36		0.5
	7.2	2.55	11.0	
	7.25	.55		
	7.3	1.02		-5.0
	7.45	.40		
6	7.6	.15	11.0	-5.0

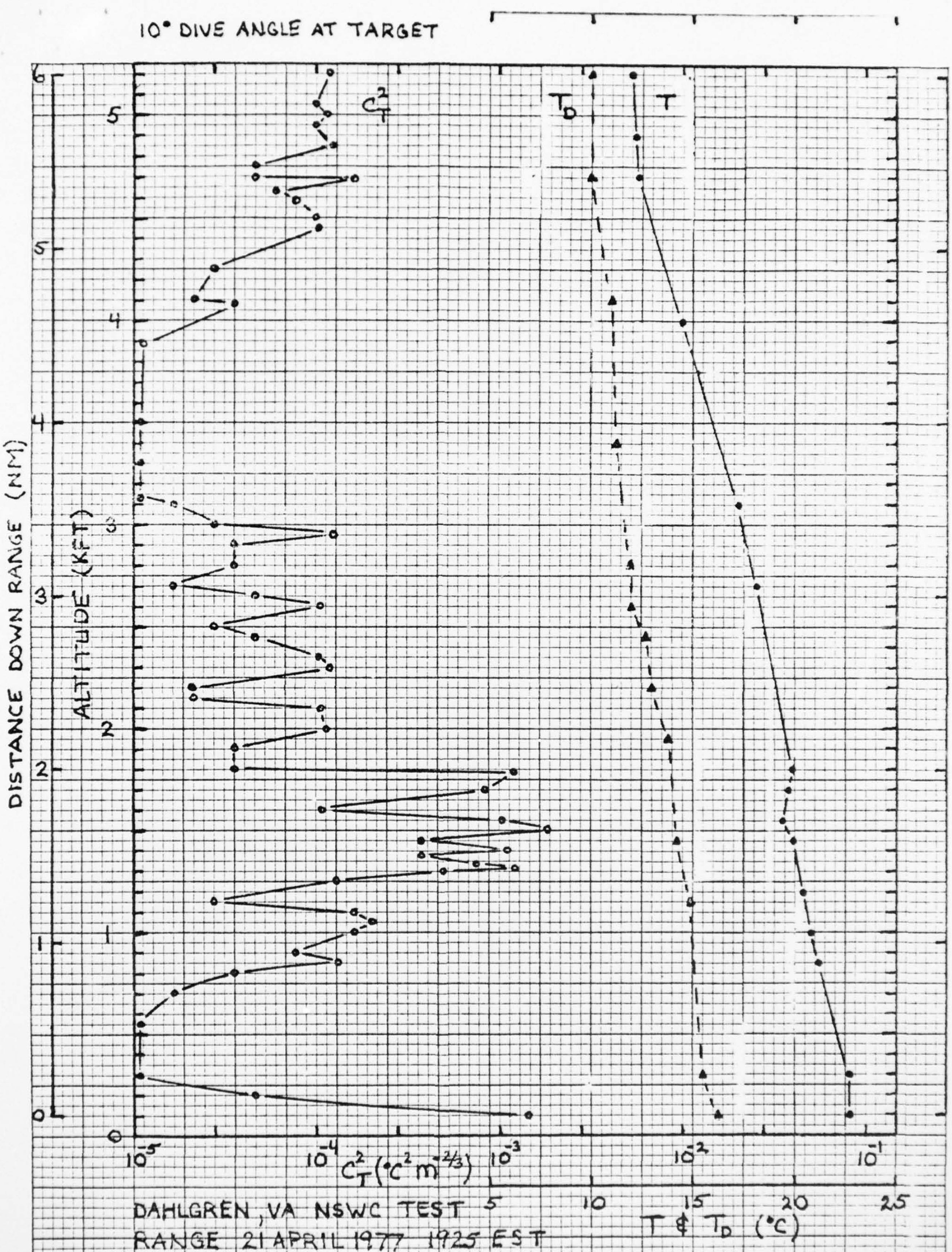

UP SPIRAL SOUNDING
C_T^2
T_D
T
ALTITUDE (KFT)
0
1
2
3
4
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
C_T^2 (°$C^2m^{-2/3}$)
5
10
15
20
25
T & T_D (°C)
DAHLGREN, VA NSWC TEST
RANGE 21 APRIL 1977 1920 EST UP SPIRAL
SOUNDING 1 NAUTICAL MILE FROM TARGET SITE

Dahlgren, VA NSWC Test Range
21 April 1977 1920 EST Up Spiral Sounding
1 NM Down Range From Target Site

Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
.750	.13	21.4	16.8
.800	.03		16.6
.850	.13		
.900	.04		
1.1	.21	20.9	16.3
1.15	.15		
1.18	.37		
1.2	.13		16.1
1.23	.43		
1.25	.21		
1.27	.13		
1.3	.29		
1.35	.13		16.0
1.37	1.07		
1.4	.15		
1.45	1.07		
1.48	.55		
1.5	1.16	19.6	15.9
1.53	.43		
1.55	.94		
1.6	.85		15.8
1.65	2.55	19.2	
1.68	.70		
1.69	1.79		
1.7	1.16		15.8
1.73	3.51	19.7	
1.75	2.21		
1.77	4.18	20.1	
1.8	5.09		14.7
1.83	3.20		
1.88	.37		
1.9	.66	20.2	
1.92	3.84		
1.95	.66		
2.0	.59		
2.01	4.53		
2.03	1.57		
2.05	2.34	19.9	14.5
2.1		20.0	14.3
2.13	.52		
2.15	.94		
2.2	.55	19.6	
2.25	.19	19.4	
2.3	.73		14.3
2.35	.52		
2.4	.26	19.4	14.0
2.45	.17		

Dahlgren, VA NSWC Test Range
21 April 1977 1920 EST Up Spiral Sounding

Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
2.47	.31		
2.5	.21	19.6	13.8
2.58	.04		
2.6	.11	19.2	
2.7	.17		
2.75	.04		
2.78	.07		
2.79	.34		
2.8	.15	19.0	13.0
2.85	.06		
2.87	.24		
2.89	.11		
2.9	.21		
2.93	.11		
2.95	.31		
2.98	.03		
3.0	.03	17.9	12.8
3.04	.26		
3.08	.013		
3.1		17.3	
3.2			12.5
3.3		16.9	
3.4		16.9	
3.5			12.3
3.64	.013		
3.65	.98	16.2	
3.7			12.1
3.8	.06		11.9
4.0	.013	15.0	11.8



DAHLGREN, VA NSWC TEST
RANGE 21 APRIL 1977 1925 EST
10° DIVE ANGLE AT TARGET FROM 5 NAUTICAL MILES DOWN RANGE

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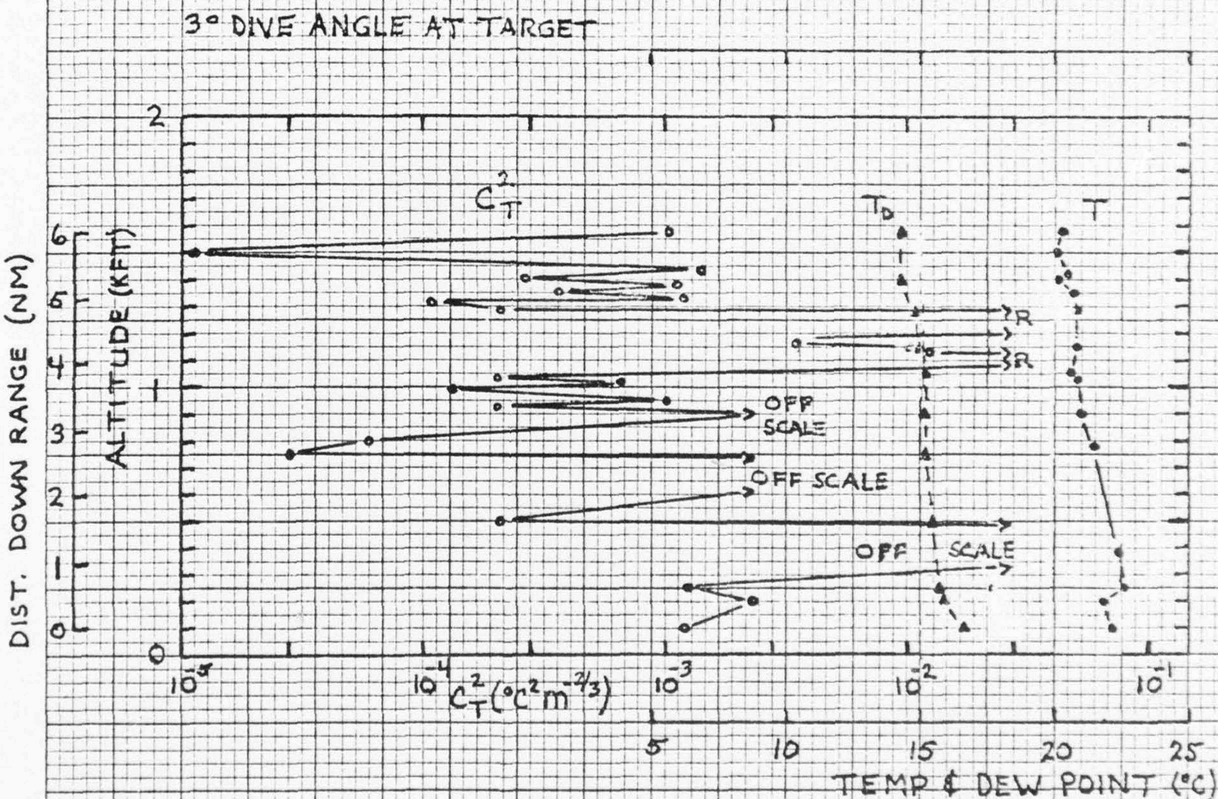
KEUFFEL & ESSER CO.

Dahlgren, VA NSWC Test Range
21 April 1977 1925 EST 10° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0	.100	2.48	22.7	16.2
	.200	.07		
	.300	.013	22.7	15.5
	.550	.013		
	.700	.03		
	.800	.06		
	.850	.22	21.2	
	.900	.09		
	1.0	.29		
	1.05	.37		
	1.1	.29		
	1.15	.05		14.9
	1.2		20.4	
	1.25	.20		
	1.3	.73		
	1.31	1.79		
	1.32	.89		
	1.38	.62		
	1.4	1.41		
	1.45	.62	19.9	14.2
	1.5	3.43		
	1.55	1.16	19.4	
	1.6	.13		
	1.7	.94	19.7	
	1.78	1.57		
	1.8	.06	19.9	
	1.9	.06		
	1.95			13.8
	2.0	.15		
	2.1	.13		
	2.15	.04		
	2.2	.04		13.0
	2.3	.16		
	2.35	.11		
	2.45	.07		12.7
	2.5	.05		
	2.6	.12		12.0
	2.65	.07		
	2.7	.03	18.1	
	2.8	.06		11.9
	2.9	.06		
	2.95	.19		
	3.0	.05		
	3.1	.03	17.3	
	3.13	.013		
	3.3	.013		

Dahlgren, VA NSWC Test Range
21 April 1977 1925 EST 10°Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} (°$C^2m^{-2/3}$)	T(C)	T_D(C)
	3.4			11.2
	3.5	.013		
	3.88	.015		
	4.0		14.5	
	4.08	.06		
	4.1	.04		11.0
	4.25	.05		
	4.45	.11		
	4.5	.10		
	4.59	.09		
	4.63	.08		
	4.68	.29		
	4.7	.07	12.3	10.0
	4.75	.07		
	4.85	.18		
	4.9	.11	12.2	
	4.95	.10		
	5.0	.15		
	5.05	.10		
6	5.2	.16	12.0	10.0



DAHLGREN, VA NSWC TEST RANGE
21 APRIL 1977 1935 EST 3° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

R = DATA COLLECTION INTERRUPTED BY
RADIO COMMUNICATION

Dahlgren, VA NSWC Test Range
21 April 1977 1935 EST 3° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0	.100	1.67	22.1	16.6
	.200	4.33	21.8	15.9
	.250	1.86	22.6	15.7
	.320			
	.390	off scale at 49	22.4	
	.490			
	.500	.38		15.4
	.610	off scale		
	.740	at 4.3		
	.750	.05		15.2
	.780		21.5	
	.800	.08		
	.900	off scale at 4.3	21.0	15.1
	.920	.37		
	.950	1.09		
	.970	.46		
	.990	.21		
	1.02	.83		
	1.03	.37	20.8	
	1.05	.79	20.6	15.1
	1.07	Radio		
	1.12			
	1.13	18.9		
	1.15	10.3	20.8	
	1.16	5.93		14.9
	1.2	Radio		
	1.28		20.8	14.8
	1.29	.38		
	1.31	.13		
	1.33	1.07		
	1.35	.60	20.7	
	1.38	1.48		
	1.4	.48	20.2	14.3
	1.42	1.8	20.5	
	1.44	2.27		
	1.5	.013	20.1	
6	1.57	1.08	20.3	14.3

Radio = Data Collection Interrupted By Radio Communication

AD-A052 077 AIRBORNE RESEARCH ASSOCIATES WESTON MA F/G 4/1
AIRCRAFT MEASUREMENTS WITHIN THE PLANETARY BOUNDARY LAYER OVER --ETC(U)
OCT 77 R MARKSON N00019-76-C-0588

UNCLASSIFIED NL

2 OF 2

AD
A052 077

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DATE
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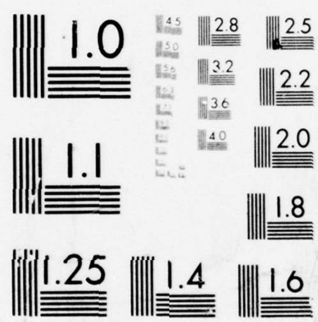
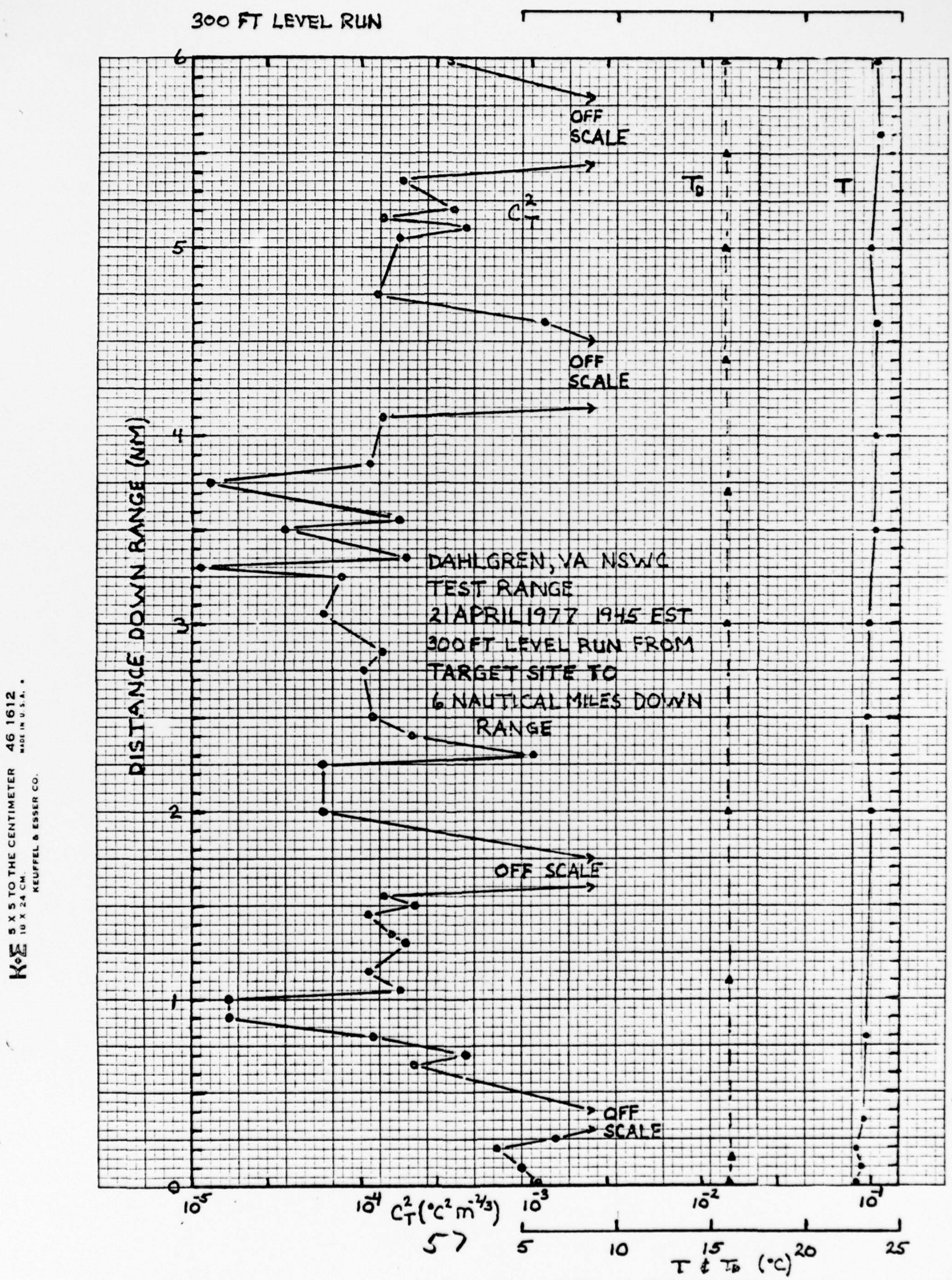


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

300 FT LEVEL RUN



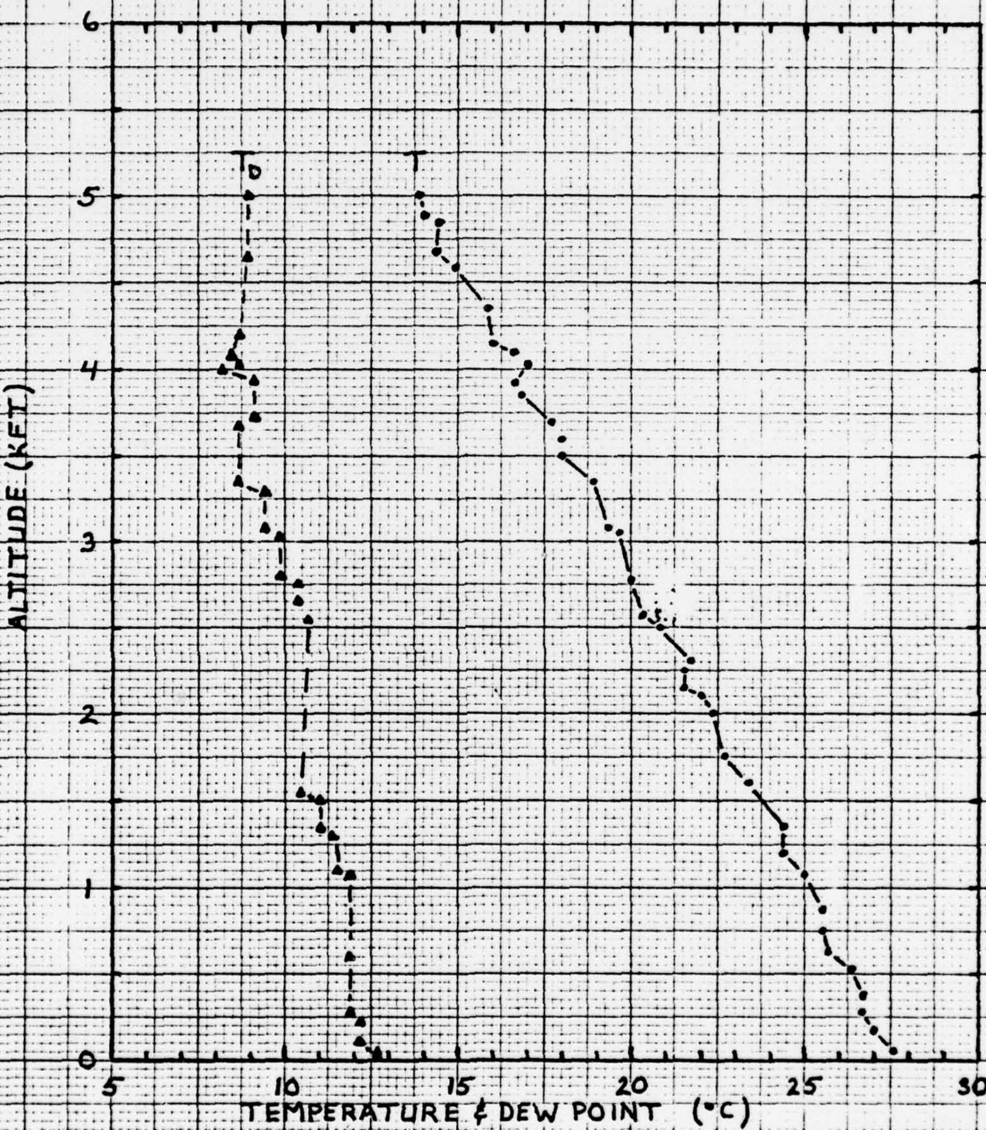
Dahlgren, VA NSWC Test Range
21 April 1977 1945 EST 300 Foot Level Run
From Target Site To 6 NM Down Range

Distance Down Range (NM)	C_T^2 x10^{-3} ($°C^2 m^{-2/3}$)	T(C)	T_D(C)
0.0	1.23	22.7	16.0
0.1	.95	23.0	
0.15			16.1
0.2	.81	22.7	
0.25	2.25		
0.3			
0.35	off scale at 4.3	23.1	
0.4			
0.65	.37		
0.7	.65		
0.8	.16	23.3	
0.9	.03		
1.0	.03		
1.05	.31		
1.1			16.0
1.15	.14		
1.3	.34		
1.35	.26		
1.45	.14		
1.5	.38		
1.55	.23		
1.6	off scale		
1.75	at 4.3		
2.0	.08	23.5	15.9
2.25	.08		
2.3	1.04		
2.4	.37		
2.5	.16	23.3	
2.75	.12		
2.85	.21		
3.0		23.4	15.8
3.05	.08		
3.25	.09		
3.3	.015		
3.35	.34		
3.5	.06	23.7	
3.55	.31		
3.7			15.8
3.75	.02		
3.85	.15		
4.0		23.7	
4.1	.21		
4.15			
4.4	off scale at 4.3		15.7
4.5			

Dahlgren, VA NSWC Test Range
21 April 1977 1945 EST 300 Foot Level Run

Distance Down Range (NM)	$C_T^2 \times 10^{-3}$ ($^\circ C^2 m^{-2/3}$)	T(C)	T_D(C)
4.6	1.59	23.7	
4.75	.19		
5.0		23.4	15.7
5.05	.30		
5.1	.65		
5.15	.21		
5.2	.58		
5.35	.31		
5.45			
5.5	off scale		15.7
5.6	at 4.3	23.9	
5.8			
6.0	.56	23.7	15.6

UP SPIRAL 3 NM DOWN RANGE



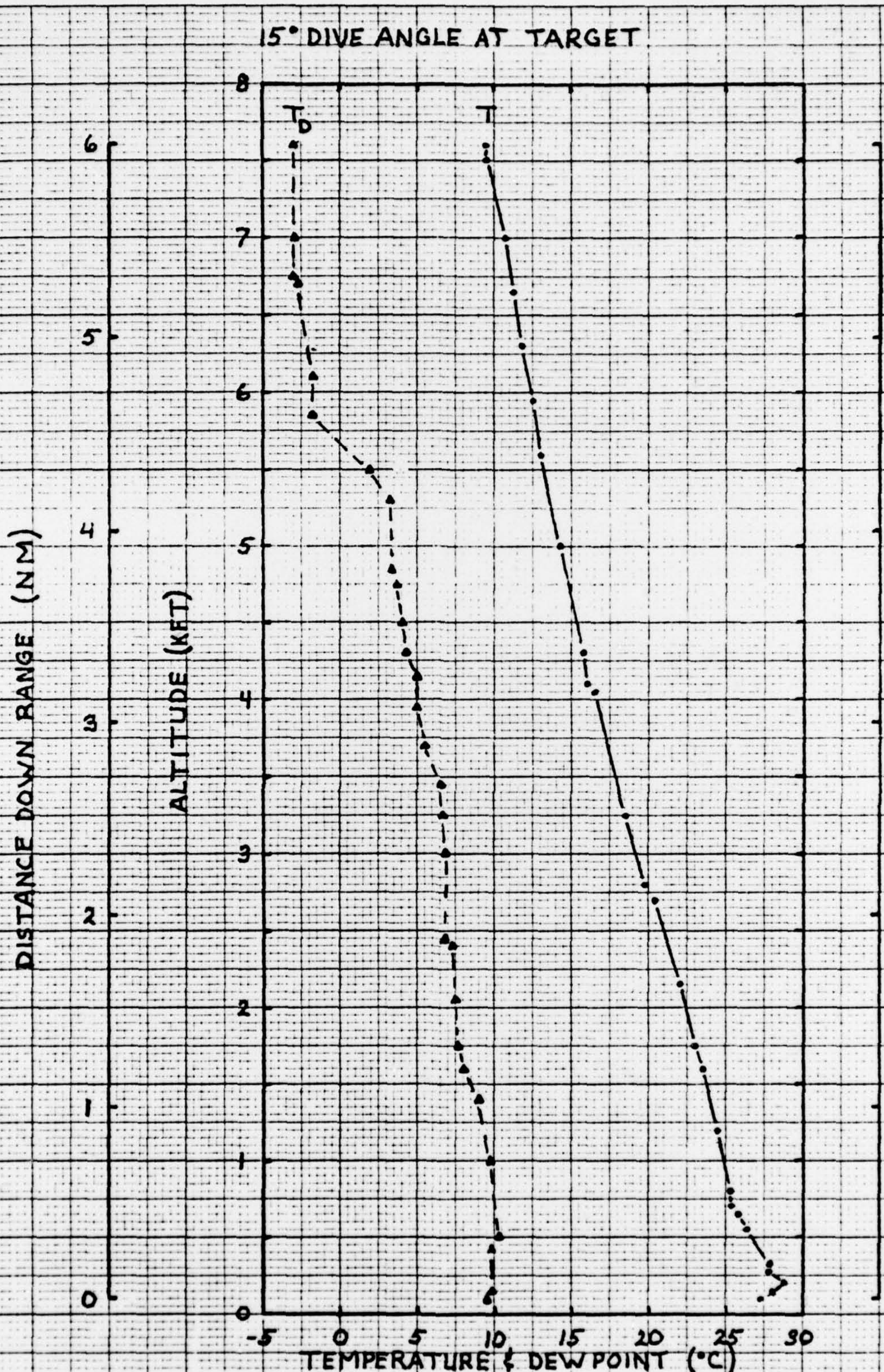
DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 1355 EST UP SPIRAL SOUNDING
3 NAUTICAL MILES DOWN RANGE FROM TARGET SITE

Dahlgren, VA NSWC Test Range
22 April 1977 1355 EST Up Spiral Sounding
3 NM Down Range From Target Site

Altitude (kft)	T(C)	T_D(C)
.010	27.6	12.7
.050	27.6	12.5
.100		12.2
.175	27.0	
.225	26.8	
.240		12.2
.275		11.8
.290	26.7	
.375	26.7	
.525	26.3	
.600		11.8
.625	25.7	
.750	25.5	
.875	25.5	
1.08	25.0	11.8
1.1		11.5
1.2	24.3	
1.3		11.3
1.35	24.3	11.0
1.5		11.0
1.55		10.4
1.6	23.3	
1.75	22.7	
1.95	22.3	
2.0	22.3	
2.1	22.0	
2.15	21.5	
2.25	21.5	
2.3	21.7	
2.35	21.3	
2.5	20.8	
2.55		10.7
2.58	20.3	
2.65		10.3
2.73	20.2	
2.75		10.3
2.78	20.0	
2.8		9.8
3.03		9.8
3.05	19.7	
3.08		9.4
3.09	19.3	
3.29		9.4
3.35	18.9	8.7
3.43	18.3	
3.5	18.0	

Dahlgren, VA NSWC Test Range
22 April 1977 1355 EST Up Spiral Sounding

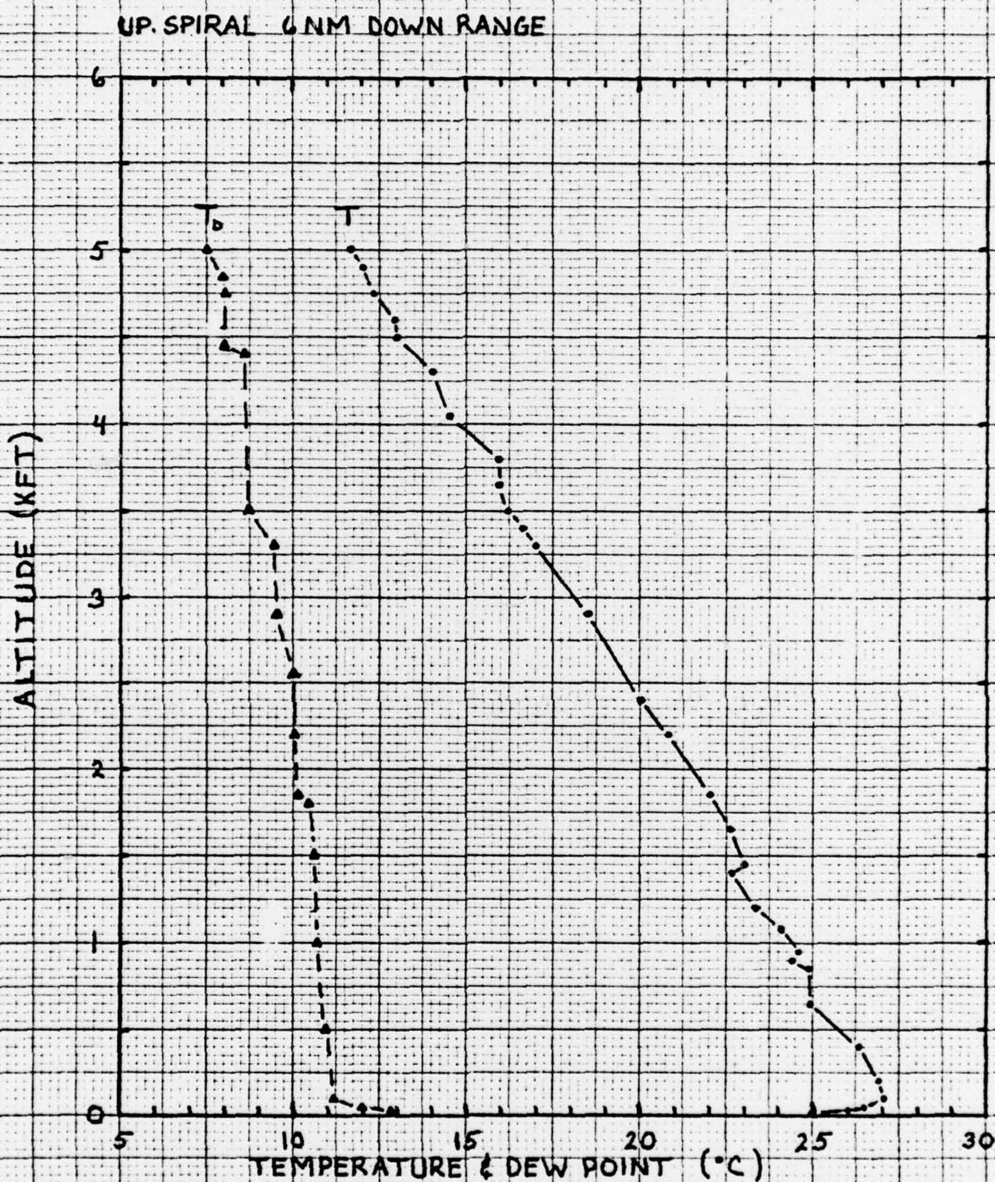
Altitude (kft)	T(C)	T_D(C)
3.6	18.0	
3.68		8.7
3.7	17.7	
3.73		9.1
3.85	16.8	
3.93	16.7	
3.95		9.1
4.0		8.2
4.03	17.0	
4.05		8.7
4.1	16.6	8.4
4.15	16.0	8.4
4.2		8.7
4.35	15.8	
4.5	15.0	
4.59	14.9	
4.63	14.5	
4.65		8.9
4.68	14.3	
4.85	14.4	
4.88	14.0	
5.0	13.8	8.9



DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 ~1405 EST 15° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
22 April 1977 1405 EST 15° Dive Angle At Target

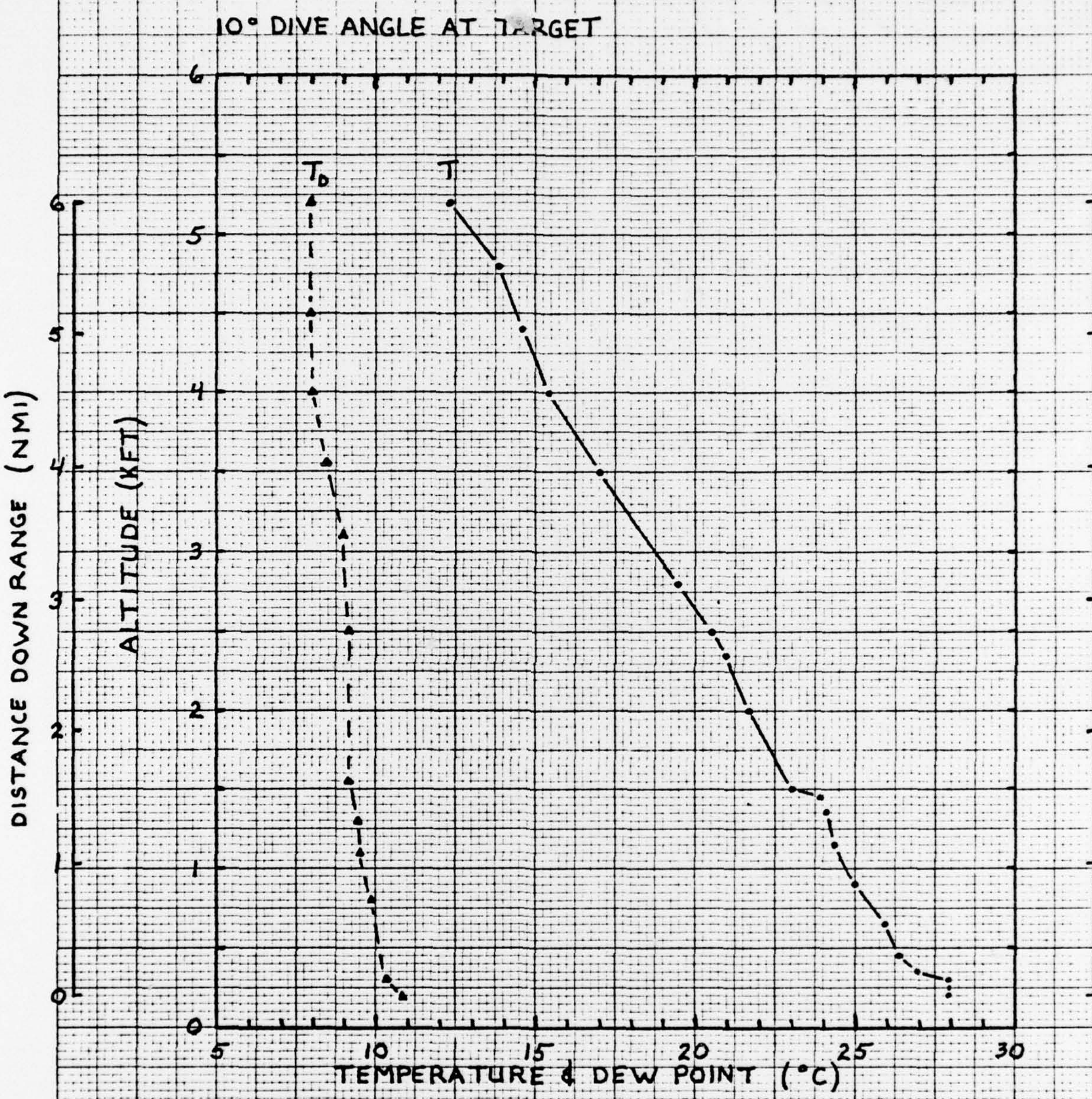
Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.100	27.3	9.5
	.150	28.0	9.9
	.200	28.7	
	.275	27.7	
	.325	27.9	
	.425		9.9
	.500		10.3
	.550	26.4	
	.650	25.8	
	.700	25.4	
	.800	25.3	
	1.0		9.7
	1.2	24.5	
	1.4		9.0
	1.6	23.5	8.0
	1.75	23.0	7.6
	2.05		7.5
	2.15	22.0	
	2.4		7.3
	2.45		6.8
	2.7	20.4	
	2.8	19.8	
	3.0		6.8
	3.25	18.5	6.6
	3.45		6.5
	3.7		5.5
	3.95		5.0
	4.05	16.5	
	4.1	16.0	
	4.15		5.0
	4.3	15.8	4.3
	4.5		4.0
	4.75		3.6
	4.85		3.4
	5.0	14.3	
	5.3		3.2
	5.5		1.9
	5.6	13.0	
	5.85		-1.9
	5.95	12.5	
	6.1		-1.9
	6.3	11.8	
	6.65	11.3	
	6.7		-2.9
	6.75		-3.0
	7.0	10.7	-3.0
	7.5	9.5	
6	7.6	9.5	-3.0



DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 ~1445 EST UP SPIRAL SOUNDING
6 NAUTICAL MILES DOWN RANGE FROM TARGET SITE

Dahlgren, VA NSWC Test Range
22 April 1977 1415 EST Up Spiral Sounding
6 NM Down Range From Target Site

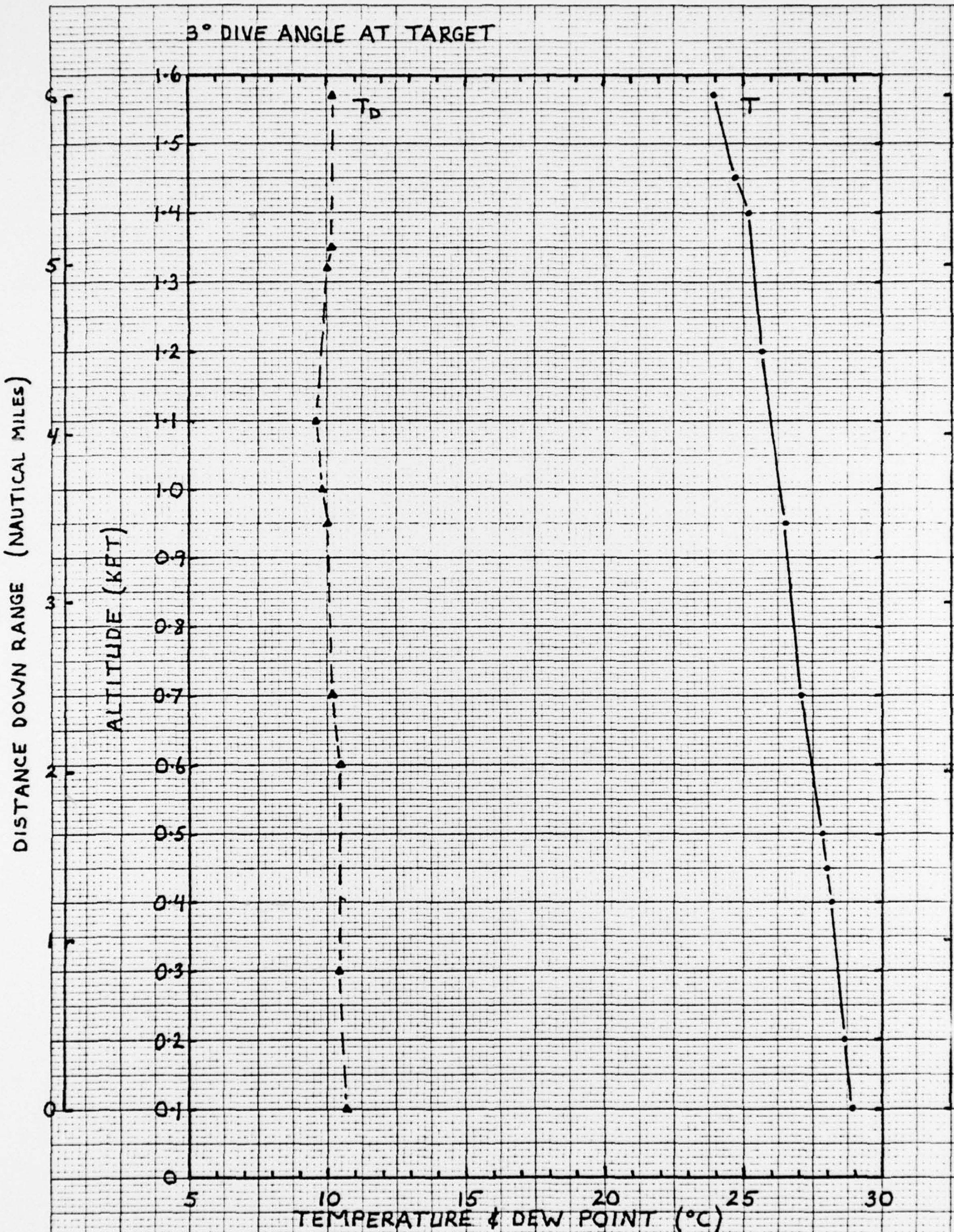
Altitude (kft)	T(C)	T_D(C)
.010	25.0	12.8
.050	26.5	12.0
.100	27.1	11.2
.200	26.9	
.400	26.3	
.500		10.9
.650	24.9	
.850	24.9	
.900	24.4	
.950	24.6	
1.0		10.7
1.08	24.1	
1.2	23.3	
1.4	22.7	
1.45	23.0	
1.5		10.6
1.65	22.6	
1.8		10.4
1.85	22.0	10.1
2.2	20.8	10.0
2.4	20.0	
2.55		10.0
2.9	18.5	9.5
3.3	17.0	9.4
3.4	16.6	
3.5	16.2	
3.58		9.2
3.6		8.7
3.65	15.9	
3.8	15.9	
4.05	14.5	
4.3	14.0	
4.4		8.6
4.45		8.0
4.5	13.0	
4.6	12.9	
4.75	12.3	8.0
4.85		7.9
4.9	12.0	
5.0	11.7	7.5



DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 ~1420 EST 10° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
22 April 1977 1420 EST 10° Dive Angle At Target

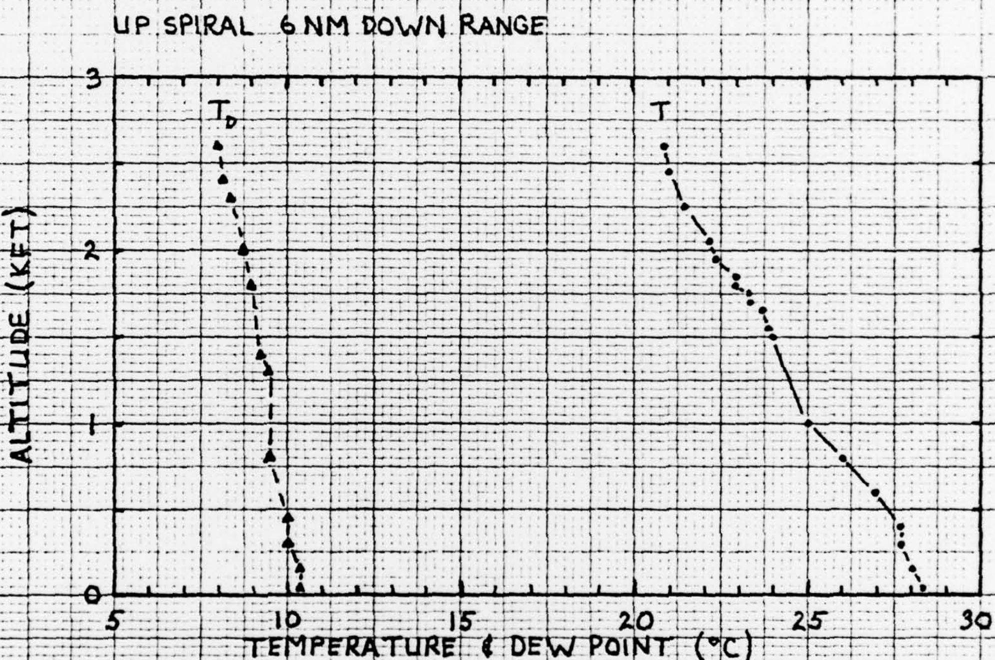
Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.200	27.9	10.8
	.300	27.9	10.3
	.350	26.9	
	.450	26.3	
	.650	25.9	
	.800		9.8
	.900	25.0	
	1.1		9.5
	1.15	24.3	
	1.3		9.4
	1.35	24.1	
	1.45	23.9	
	1.5	23.0	
	1.55		9.1
	2.0	21.7	
	2.35	20.9	
	2.5	20.5	9.1
	2.8	19.4	
	3.1		8.9
	3.5	17.0	
	3.55		8.4
	4.0	15.4	8.0
	4.4	14.6	
	4.5		7.9
	4.8	13.8	
6	5.2	12.3	7.9



DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 ~1430 EST 3° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA NSWC Test Range
22 April 1977 1430 EST 3° Dive Angle At Target

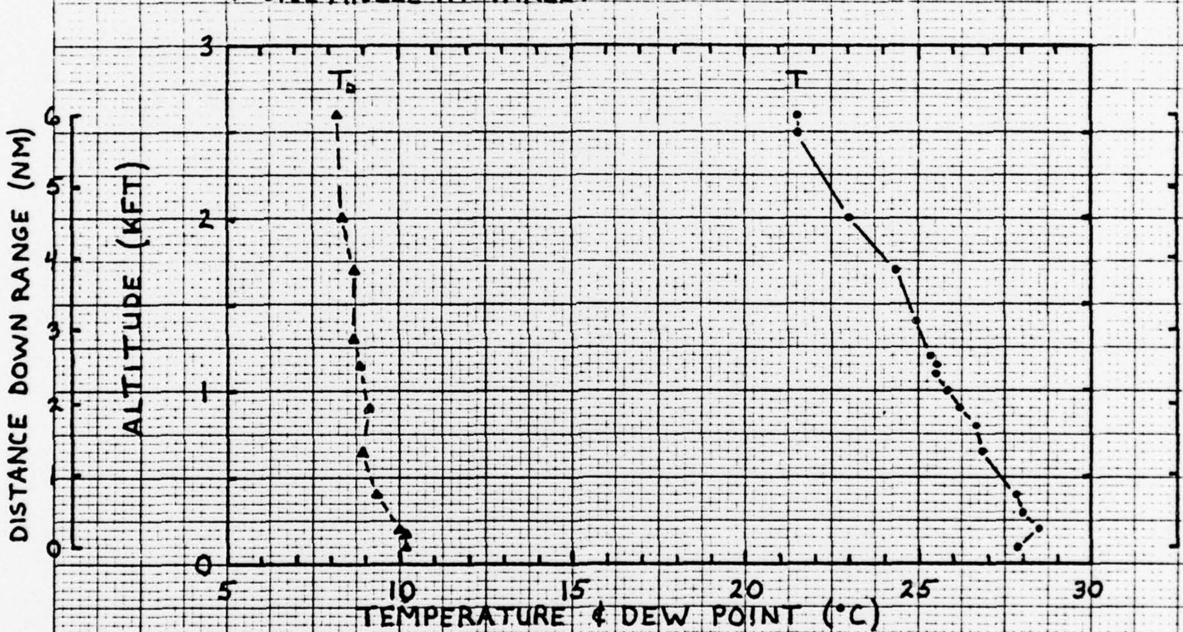
Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.100	28.9	10.7
	.200	28.7	
	.300		10.4
	.400	28.2	
	.450	28.0	
	.500	27.8	
	.600		10.4
	.700	27.1	10.2
	.950	26.5	10.0
	1.0		9.8
	1.1		9.6
	1.2	25.7	
	1.32		10.0
	1.35		10.2
	1.4	25.2	
	1.45	24.7	
6	1.57	23.9	10.2



DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 ~1600 EST UP SPIRAL SOUNDING
6 NAUTICAL MILES DOWN RANGE FROM TARGET SITE

Dahlgren, VA NSWC Test Range
22 April 1977 1600 EST Up Spiral Sounding
6 NM Down Range From Target Site

Altitude (kft)	T(C)	T_D(C)
.030	28.3	10.3
.150	28.0	10.3
.300	27.7	10.0
.400	27.7	
.450		10.0
.600	26.9	
.800	26.0	9.4
1.0	25.0	
1.3		9.4
1.4		9.2
1.5	24.0	
1.55	23.8	
1.65	23.7	
1.7	23.3	
1.75	23.3	
1.8	22.9	8.9
1.85	22.9	
1.95	22.3	
2.0		8.7
2.05	22.2	
2.25	21.4	
2.3		8.3
2.4		8.1
2.45	21.0	
2.6	20.8	7.9



DAHLGREN, VA NSWC TEST RANGE
22 APRIL 1977 1605 EST 4° DIVE ANGLE AT
TARGET FROM 6 NAUTICAL MILES DOWN RANGE

Dahlgren, VA Test Range
22 April 1977 1605 EST 4° Dive Angle At Target

Distance Down Range (NM)	Altitude (kft)	T(C)	T_D(C)
0	.100	27.8	10.2
	.190		10.2
	.200	28.5	10.0
	.300	28.0	
	.400	27.8	9.3
	.650	26.8	8.9
	.800	26.7	
	.900	26.2	9.1
	1.0	25.8	
	1.1	25.5	
	1.15	25.5	8.8
	1.2	25.3	
	1.3		8.7
	1.4	24.9	
	1.7	24.3	8.7
	2.0	23.0	8.3
	2.5	21.5	
6	2.6	21.5	8.2